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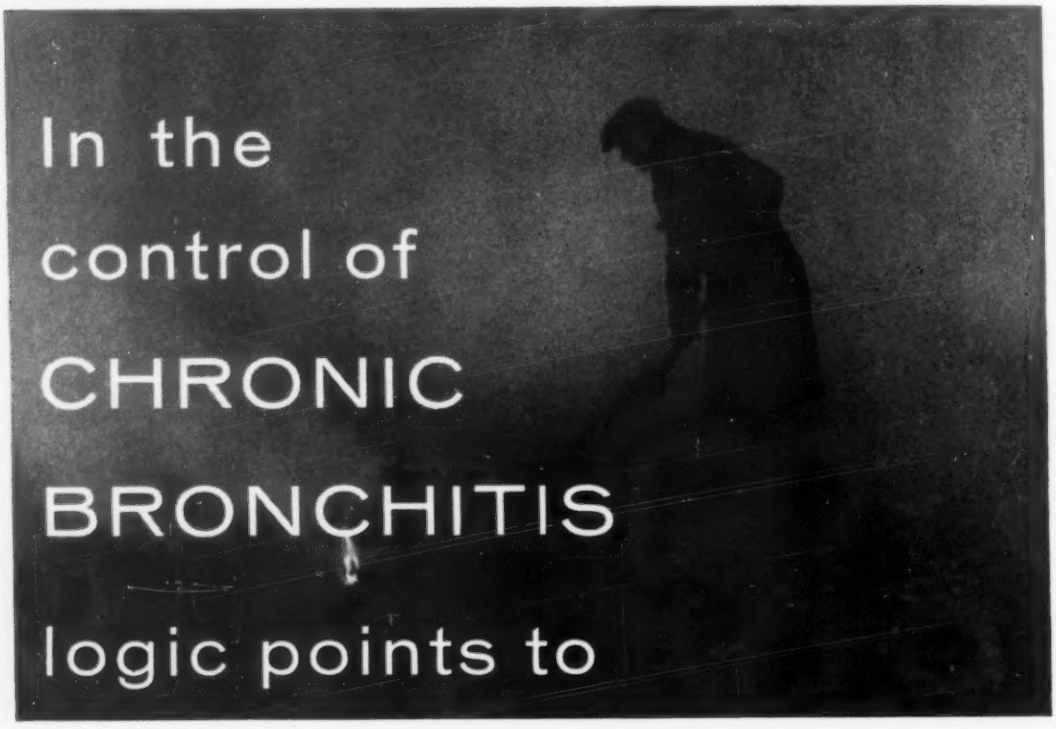

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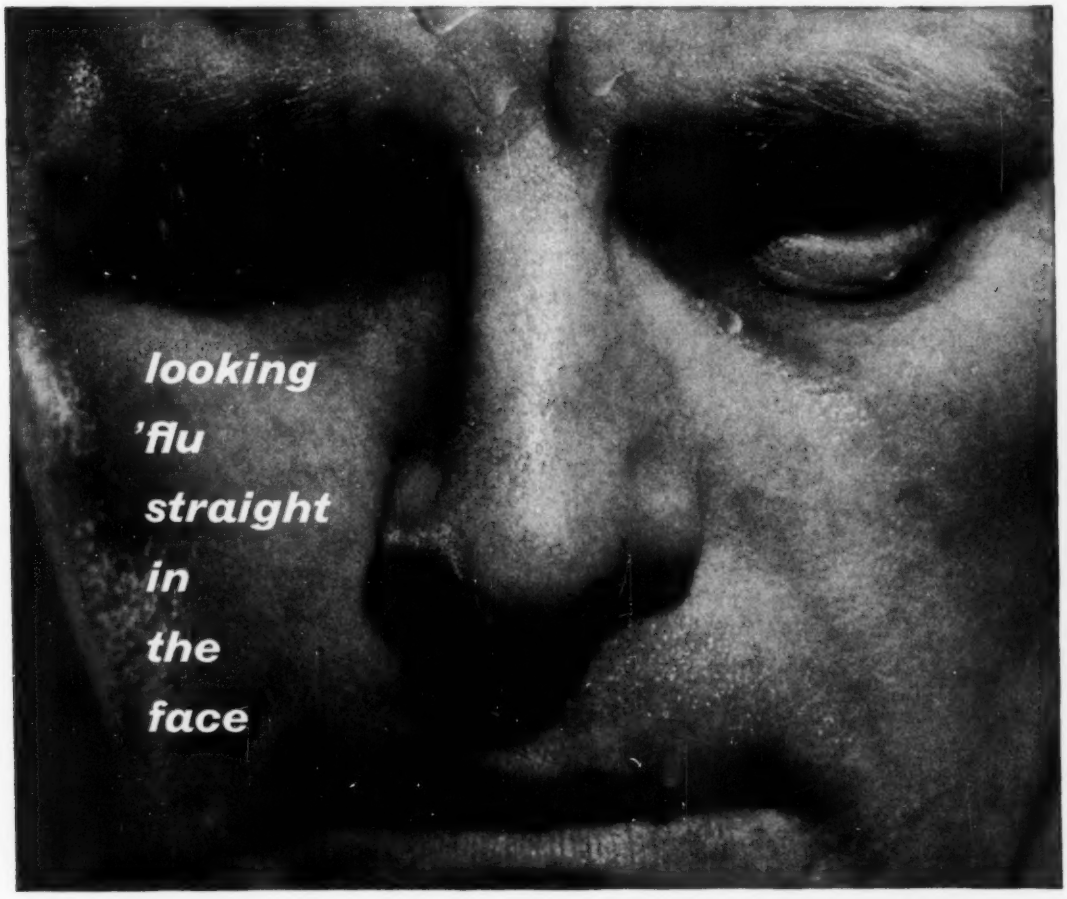

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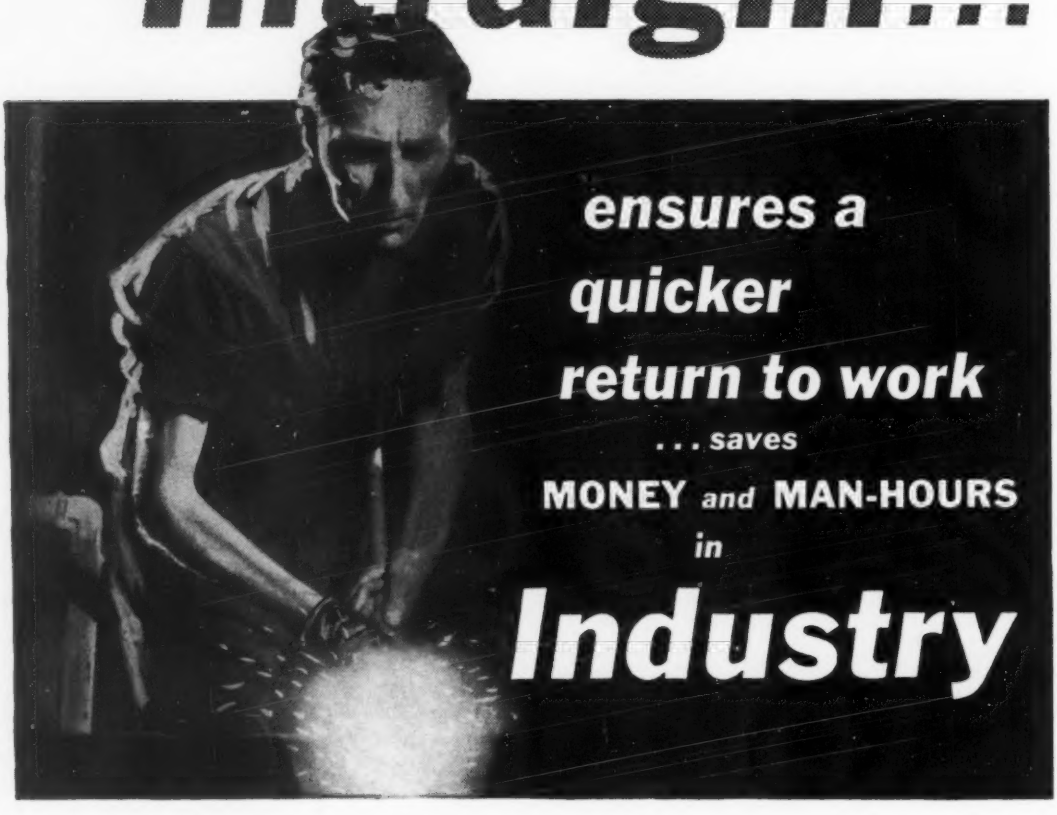

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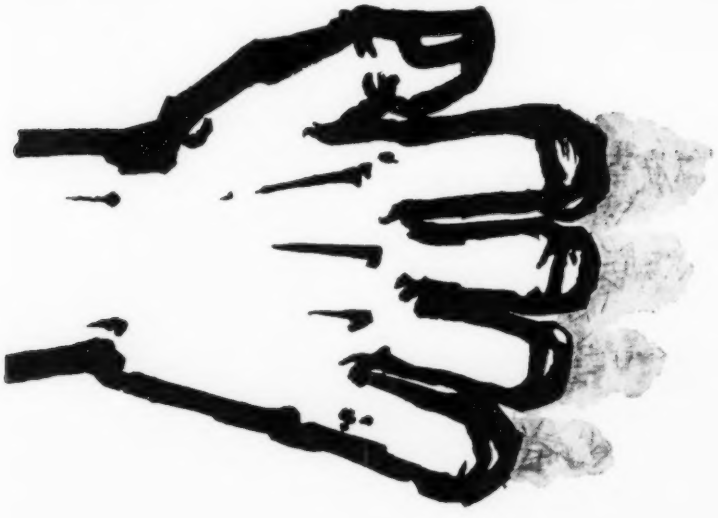

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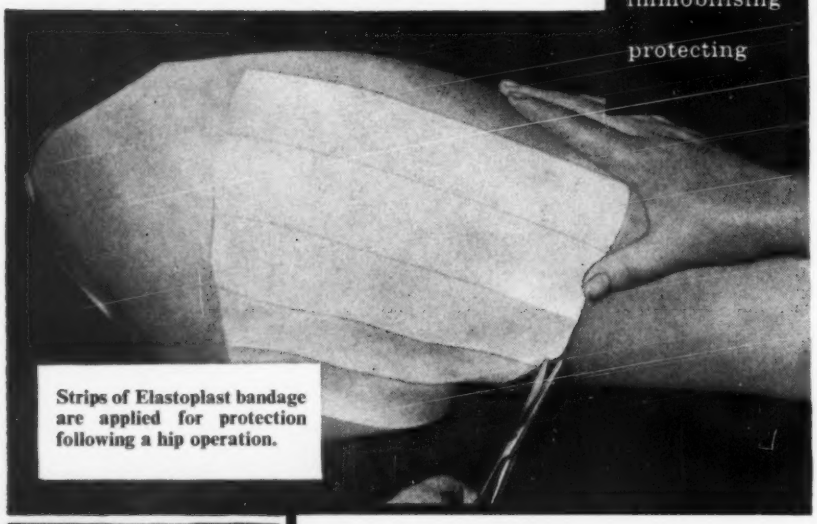

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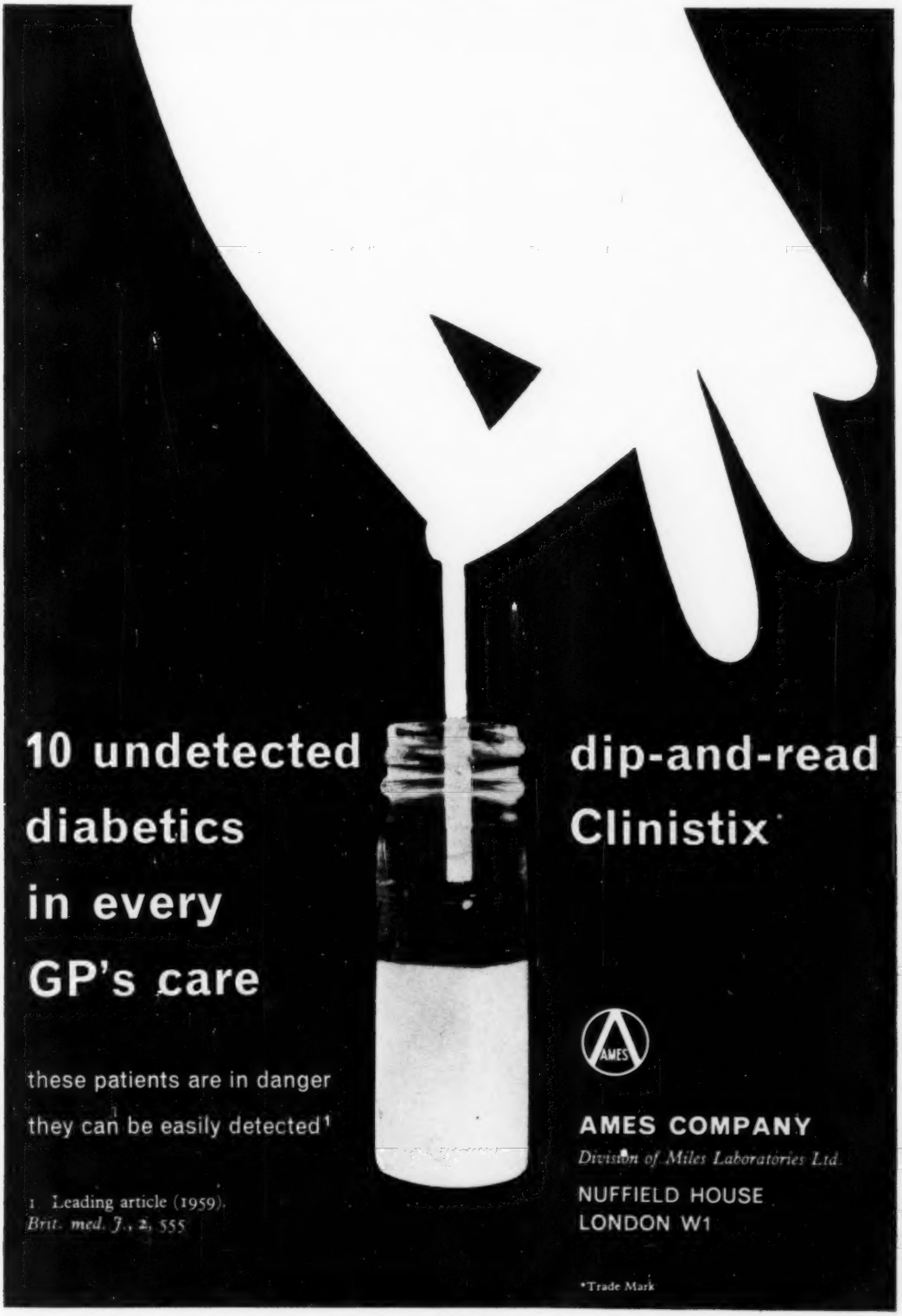
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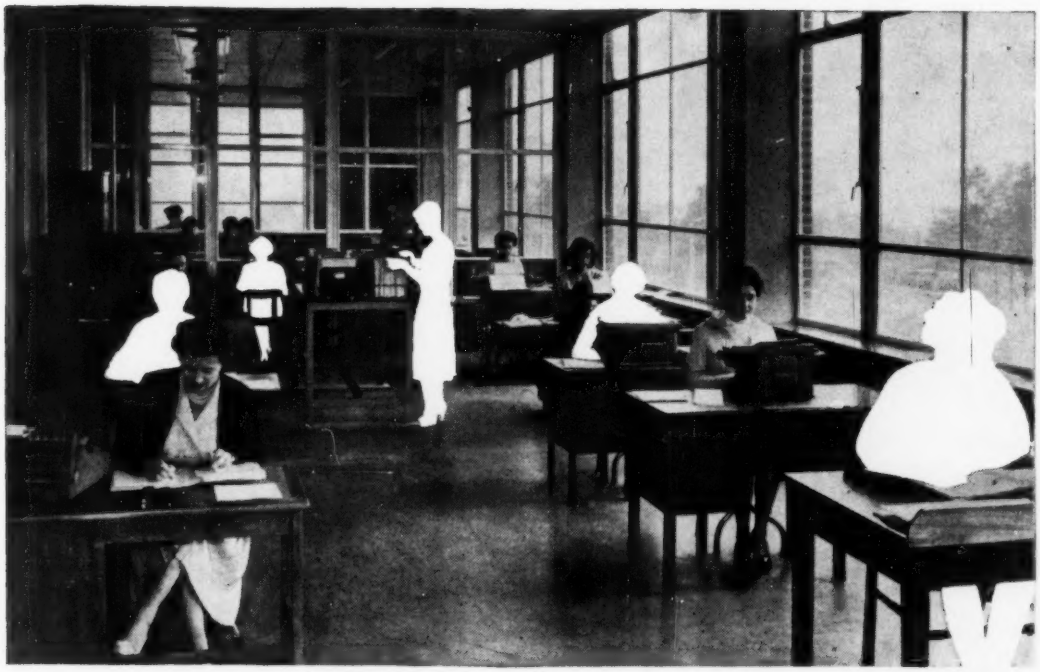

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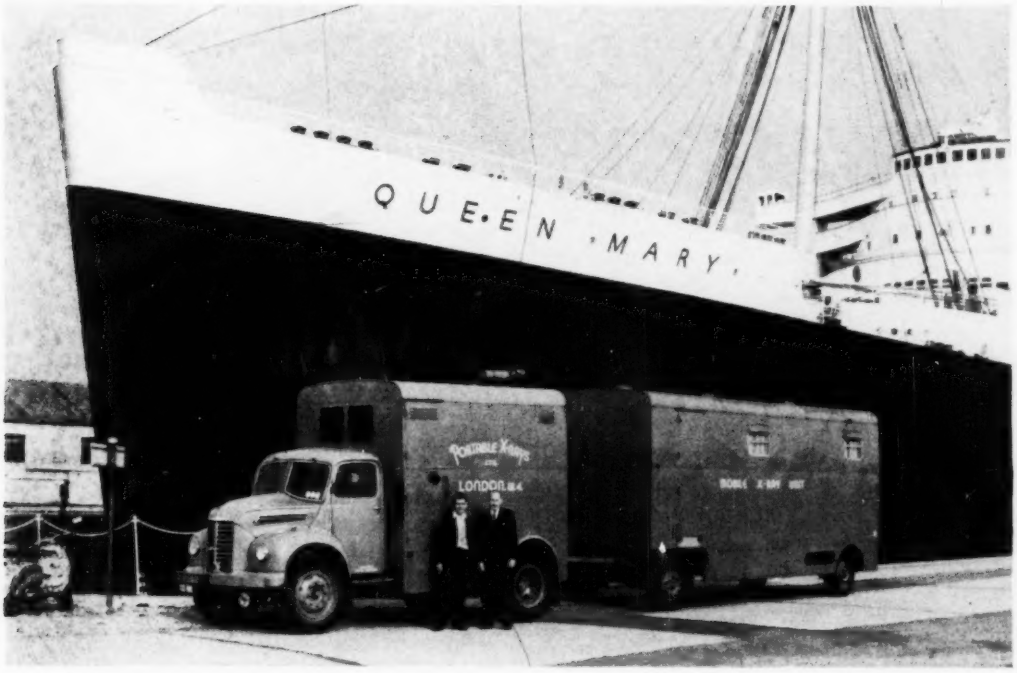

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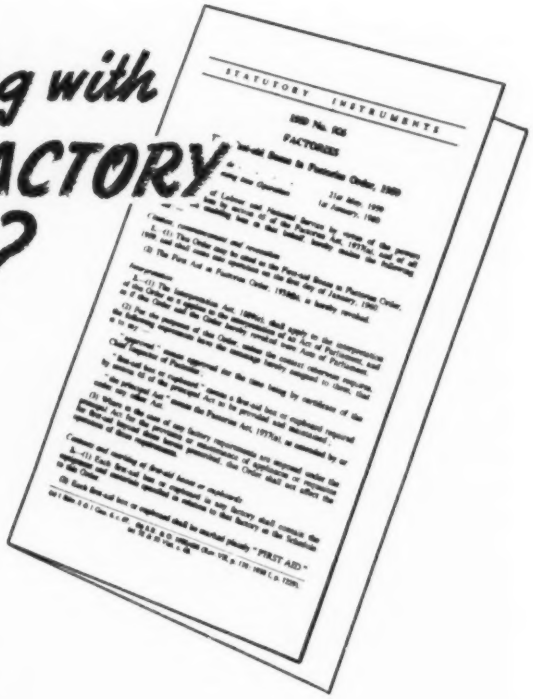
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Brit. J. industr. Med., 1960, **17**, 247.

THE RELATION BETWEEN LUNG DUST AND LUNG PATHOLOGY IN PNEUMOCONIOSIS*

BY

G. NAGELSCHMIDT

From the Ministry of Power, Safety in Mines Research Establishment, Sheffield

(RECEIVED FOR PUBLICATION OCTOBER 7, 1959)

Methods of isolation and analysis of dust from pneumoconiotic lungs are reviewed, and the results of lung dust analyses for different forms of pneumoconiosis are presented.

A tentative classification separates beryllium, aluminium, abrasive fume, and asbestos, which cause interstitial or disseminated fibrosis from quartz, coal, haematite, talc, kaolin, and other dusts, which cause a nodular or focal fibrosis which may change to forms with massive lesions. The data suggest that in the first, but not in the second, group the dusts are relatively soluble; only in the second group do amounts of dust and severity of fibrosis go in parallel for a given form of pneumoconiosis. In classical silicosis the quartz percentage is higher and the amount of total dust much lower than in coal-miners' pneumoconiosis. Mixed forms of both groups occur, for instance, in diatomite workers. The need for more research, especially in the first group, is pointed out.

Pneumoconiosis has been defined as "a diagnosable disease of the lungs produced by the inhalation of dust" (International Labour Organization, 1953) and in pneumoconiosis research the study of the dust found in the lungs after death is one of the means by which one tries to understand the development of the disease. Important advances in the technique of dust examination have been made in the past 20 years; *x*-ray diffraction methods were introduced for mineral analysis and are now well established; electron microscopy was used to examine the shapes of dust particles *in situ* or after their isolation, and to measure their size distributions. Techniques for such work are still being developed.

In order to yield the maximum information, the results of lung dust analyses need to be combined with pathological descriptions of the lungs and with a knowledge of the dust exposures. As dust exposures are usually of the order of decades such correlations are only possible to a limited extent and in certain cases. As the lung changes found appear to depend, among other things, on the concentration and composition of the deposited dust, it is necessary not only to ascertain the lung dust composition but also the total amounts of dust in the lungs. As it is not usually possible to use the complete lungs for analysis this entails considerations of sampling.

This field is reviewed in the present paper. The first part deals with methods of sampling, isolation, and analysis of lung dust and with the way in which the results of the analyses can be expressed. In the second part separate disease entities, such as silicosis and pneumoconiosis of coal-miners, are reviewed on the basis of results from the literature and of work from our laboratory. The third part contains conclusions and speculations drawn from the data.

Methods

Sampling of Lungs.—Where only a small surgical specimen or a few grams of lung tissue are available for study, sampling is relatively easy, but if a complete pair of lungs is obtained at autopsy, the position is different. Very few studies have so far been concerned with details of the distribution of dust in different locations in the lung or in lymph nodes inside and outside the chest (Albertini, Brandenberger, and Rüttner, 1947; Gerstel, 1935). In general, so far, the main problem has been to determine the total amount of dust in the lungs and its composition.

Badham and Taylor (1938) discussed the problem of sampling. They considered it inadvisable to destroy the entire lung, as parts might be needed as medico-legal evidence in contentious compensation claims. In order to allow for disparities between the right and left lungs they divided each lung in the axillary plane into equal halves and used one half of each lung for analysis. King, Maguire, and Nagelschmidt (1956), in cooperation with Professor Gough, used one complete lung, usually the

* A brief account of the main results of this paper was given at the International Pneumoconiosis Conference, Johannesburg, in February 1959, and will be published in its Proceedings.

right, for analysis, while the left lung was preserved for histological examination, including the preparation of large sections (Gough and Wentworth, 1949). Lungs were used only if there were no gross dissimilarities between right and left lungs. Both methods may lead to some error.

Gerstel (1935) gave data about the dust content of right and left lungs which had been analysed separately. In 28 cases of silicosis without tuberculosis (the German use of "silicosis" is discussed below) from a variety of occupations, including mining of iron ore, coal, and pottery work, the total silica in both lungs ranged from 2-18 g. A calculation from his data showed that the mean value for the right lungs was only 3% higher than that for the left lungs, and that the standard deviation of the weight of dust in the right lung as a percentage of the total dust in both lungs, which can be taken as a measure of the uneven distribution of dust in right and left lungs, was 16%.

Our own analyses of four pairs of lungs (kaolin, talc, electrode worker, and coal-miner), with massive lesions but without gross disparities between right and left lung, have shown practically no differences in composition, and differences of the order of 10-20% in total dust expressed as a percentage of the dried right and left lung. The lung weights themselves differed more but, as they were known, allowance could be made for determining the total dust in both lungs.

At least a third, and preferably half, the lung material from a pair of lungs should be available for analysis if the total amounts of dust in them are to be determined. For a knowledge of dust composition alone smaller samples are adequate. Apart from the lungs themselves, the peribronchial and hilar lymph nodes also often contain dust, and their study can lead to additional information.

The type of sampling will always depend on the kind of information required. Gerstel (1935) sampled separately a number of silicotic lesions in a given pair of lungs in order to study the relation between the size of the fibrous mass and its silica content. Massive lesions and the remainder of the lung may be sampled separately in order to deduce the mode of formation of massive lesions from any differences that might be found in the composition of the two lung dust samples; the dust in the lymph nodes in the chest and elsewhere may also be analysed to study the effect of size on mobility within the lymphatic system.

Isolation of Lung Dust.—A variety of methods are available for separation of the dust from the lungs or gland tissue in which it is embedded. If chemical alteration of the dust by acid or alkali is to be minimized, purely mechanical methods can be used, as described by Sundius and Bygdén (1938). The wet lung tissue was grated with a file, the detritus washed with water, alcohol, and benzene, and fractions of different density were separated by centrifuging with heavy liquids. Although this method is the mildest one, it has the disadvantage that it only recovers part of the dust and is therefore not suitable for quantitative studies.

Another method which does not affect the dust and any calcification in the lung is the treatment of the lungs with water-free formamide at 135°C. This method has been developed and described by Thomas and Stegemann (1954).

A method which is almost equally mild for minerals and suitable for coal of high rank, *i.e.* anthracite and steam coal, is treatment with concentrated (30% w/v.) H_2O_2 (Sundius and Bygdén, 1938). Fat is not destroyed by H_2O_2 and is removed by alcohol or acetone extraction either before or after the H_2O_2 treatment proper, preferably on both occasions. Coal of low rank, *i.e.* bituminous coal or lignite, is partially attacked by H_2O_2 and therefore it is not possible to use this technique for quantitative determination of coal dusts in general. Digestion of lung tissue with alkali (King and Gilchrist, 1945) is fairly satisfactory for the isolation of coal irrespective of its rank. The use of concentrated HCl for fresh and formalin-fixed (animal) tissue has been described by Wright (1957).

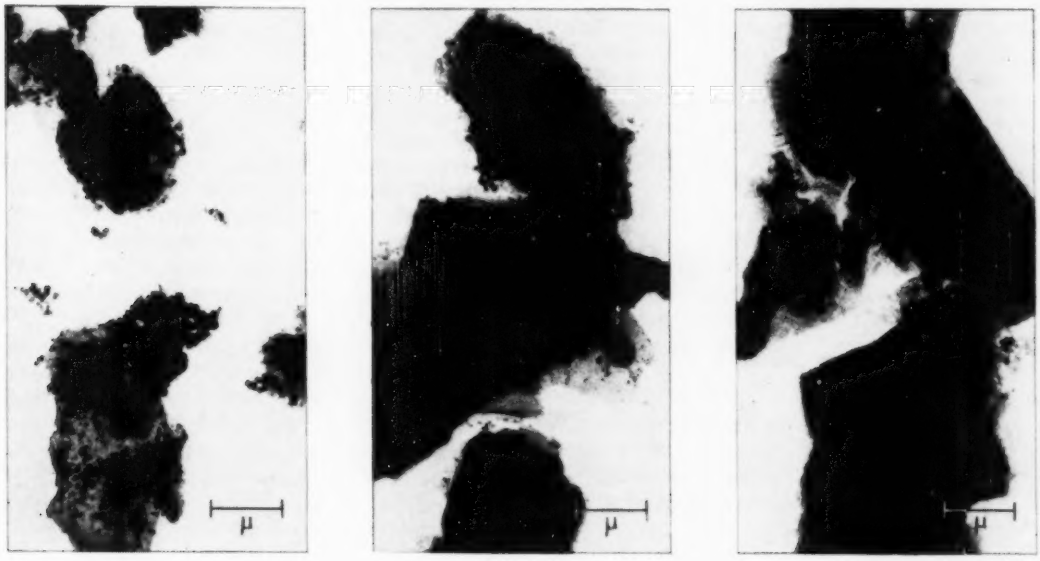
For mineral analysis the residue obtained after digestion of the lung with H_2O_2 can be ashed at 380°C. and the ash extracted with suitable solvents to remove endogenous lung salts (Nagelschmidt and King, 1941). The extracting medium can be varied according to the type of lung dust. A prolonged extraction with cold, or a brief one with hot, 2N HCl removed most of the Fe_2O_3 and P_2O_5 from coal-miners' lung residues with losses of only a few per cent of the total Al_2O_3 and SiO_2. Treatment with cold N/10 HCl, used in the case of a talc residue, did not quite remove lung salts but left the talc unattacked (Fig. 1).

Another method, enzyme digestion (Hicks, McElroy, and Warga, 1937), is difficult to apply to formalin-hardened tissue and is very slow. But, if ashing is permissible, it is also possible to ash the ground, dried lung powder in shallow layers in trays in an electric muffle at 380°C. This requires more time but less labour than H_2O_2 treatment followed by ashing.

More destructive methods such as treatment with concentrated nitric acid followed by ignition of the dust at temperatures of the order of 600°C.-700°C. have been used extensively in the past (Jones, 1933), but this can lead to some loss or alteration of the mineral dusts, and the results must be interpreted with caution (see below).

In conclusion, lung dust can be isolated in various ways and the choice will depend on the means available. A specialized laboratory which is equipped for formamide extraction may find this method the best, but very similar results can be obtained by H_2O_2 attack or combined methods. This can be illustrated by recent comparative work on coal-miners' lung dust analyses carried out jointly in two laboratories. Professor K. Thomas in Göttingen (Laboratory A) prepared four samples of vacuum-dried ground lung suitable for dust isolation by the formamide method and sent part of the material to the Safety in Mines Research Establishment in Sheffield (Laboratory B) where coal was determined by alkali digestion, and the mineral matter, in a separate sample, by ashing, followed by extraction with 2N HCl. The results are given in Table 1 and show that similar values were obtained by different methods of analysis.

FIG. 1.—Ash from talc lung.



(a) Untreated; the talc plates are covered by endogenous lung salts.

(b) Extracted with 0·2N HCl; the thin talc plates are intact but a little endogenous lung salts are still present.

c) Extracted with 2N HCl; the lung salts are completely removed but the thinnest talc plates are attacked.

TABLE 1

LUNG DUST ANALYSES CARRIED OUT BY DIFFERENT METHODS IN LABORATORIES A AND B

Sample Number	Percentage of Dried Lung			
	Coal		Mineral Matter	
	A	B	A	B
1	15·1	15·8	5·2	4·4
2	5·7	5·3	2·20	1·94
3	25·9	26·7	1·60	1·66
4	15·5	15·8	0·90	0·98

Composition of Lung Dust.—Lung residues usually consist of particles too small to be identifiable by petrological microscope techniques. The mineral composition of lung dust must therefore be determined by the methods developed for the analysis of clays and other materials of similar size. *X*-ray diffraction is the most important of these and can be used for quantitative analysis by film and diffractometer methods (Klug and Alexander, 1954). Although normal petrological microscope technique is not applicable, limited information can be obtained by dispersion staining (Schmidt, 1955). For quartz determination, chemical methods as accurate as *x*-ray methods have been developed (Nagelschmidt, 1956). Differential thermal analysis and infra-red absorption technique have also been used for quartz analysis. The extensive literature on this subject has been reviewed by Brasch (1956).

The mineral composition of lung dust can be determined by direct methods and also by a complete chemical analysis. This requires a knowledge of the chemical composition of the individual members and its alteration by the method used for isolating the dust. For fairly accurate work a combination of more than one method, for instance *x*-ray diffraction and chemical analysis, is usually more successful than the use of one particular method.

For complete chemical analysis of the constituent oxides of a lung residue the semi-micro methods, used in silicate analysis, are appropriate (Shapiro and Brannock, 1956). A complete scheme has also been developed by Stegemann and Fitzek (1954); and Fitzek and Stegemann (1957).

Methods of Expressing the Results of Analysis.—The best way to present the results of lung dust analysis is to give the amounts, in grams, of the different constituents in any given lung. This can be done if the total lung weight is known and if a sufficiently large sample of it has been used either for dust isolation or for preparing homogeneous dried ground lung for analysis. If the results are only expressed as a percentage of dried lung they may depend to a considerable extent on the pathological condition of the lung (Collins and Dible, 1935). These authors describe a case in which the total silica in the right and left lungs was about the same (0·69 and 0·64 g.) but, because of pneumonic consolidation, the silica expressed as a percentage of dried lung was 0·53% in the pneumonic and 1·02% in the other lung. Similar considerations apply to the results when given as a

percentage of ash. Calcification can affect the ash weight considerably and Collins and Dible (1935) give an example of a silicotic lung in which the ash content of different samples varied between 7 and 35% of dried lung according to the amount of calcification present.

These are, however, extreme examples. Results expressed as a percentage of dried lung are of value, especially if one is interested in averages and orders of magnitude for a number of analyses rather than in any single lung dust analysis.

Different Forms of Pneumoconiosis

The different forms of pneumoconiosis are difficult to classify. From the description of the kind of fibrosis the following appear to be distinguishable:

(1) Hyaline-nodular form (classical silicosis).

(2) Simple pneumoconiosis as seen, for example, in coal-miners in South Wales.

(3) Forms of fibrosis intermediate between (1) and (2) (as seen in haematite miners, foundry workers, ceramic workers, etc.). The German term "Mischstaubsilikose" probably covers groups 2 and 3.

(4) Diffuse interstitial fibrosis (as seen in asbestosis, aluminosis, Shaver's disease, and in chronic berylliosis).

In each of these four groups there is a range of lung changes which corresponds to increasing volume and severity of the fibrosis, culminating, at least for the first three groups, in the formation of areas of massive fibrosis.

Other classifications are sometimes based on the type of dust or the industry concerned. Asbestosis and classical silicosis are perhaps the best defined entities; pneumoconiosis of coal-miners is usually described as "silicosis" on the Continent, and the term "pneumoconiosis" as used for compensation purposes in Great Britain includes, for instance, silicosis of rock workers in coal-mines.

There exists a reasonable amount of information from lung dust analyses in classical silicosis and in the pneumoconiosis of coalworkers, and these will be dealt with first, followed by data on pneumoconiosis in the absence of quartz. Then follow results from red lungs in which iron oxide is the chief constituent, and for miscellaneous forms of lung dust disease, including asbestosis, where information is scanty. Emphasis will mainly be laid on lung dust analyses in the advanced stages of disease, where massive lesions predominate.

Classical Silicosis.—Silicosis is the best known of all the different forms of lung dust diseases. It has been studied and described in many industries and many countries. Perhaps the most detailed work was done in South Africa, where the introduction of mechanical drills towards the end of the last century caused a very large amount of silicosis in the gold mines of the Rand.

Silicosis is characterized by a specific type of lesion, the silicotic nodule (Simson, 1931; Belt, Ferris, and King, 1940), and it is caused by dusts which contain a substantial proportion of quartz. Although many studies of the lung dust in silicosis exist, there are only a few which can be used to correlate the amount and composition of the dust in the lungs with the pathological picture. Our data have been taken from three studies, one from South Africa, one from Australia, and one from Great Britain. In all three the pathological descriptions were unequivocal and corresponded to classical silicosis. Whole lungs were used for analysis, and from the methods of isolation described it was possible to estimate such losses of material as may have occurred. Furthermore, quartz determinations as distinct from total silica determinations were carried out in two of the series and in the third the proportions of quartz could be estimated from complete silicate analyses of the lung dust and other information obtained subsequently.

SOUTH AFRICAN GOLD-MINERS.—Simson and Strachan (1935) isolated the mineral residues from 38 lungs of South African gold-miners by treatment with concentrated nitric acid, followed by ignition, a method introduced by Jones (1933). They recorded the weight of dust isolated, and in a later paper (Robertson, Simson, and Strachan, 1937) complete chemical analyses of 10 of these residues were given and interpreted in terms of minerals in the residues, which were essentially quartz and sericite. They classed the fibrosis simply as slight, moderate, marked, and very marked. Their second paper gave the analysis of an untreated lung ash sample; a comparison of the silica/alumina ratio of straight lung ash with the silica/alumina ratio of a nitric acid residue of the same lung showed that about 23% of the Al_2O_3, mainly from sericite, was lost in the nitric acid digestion. This had a slight effect on total recovery and tended to make the quartz estimate, which is based on the ratio $SiO_2 : Al_2O_3$, too high. The residues also contained from 1-10% P_2O_5, indicating incomplete removal of phosphate from the lung salts.

For our calculations the amounts of dust found were used without further corrections on the assumption that the losses from the attack on the sericite balanced the gains due to incomplete removal of phosphate. As a check on the lung dust composition, residues were isolated by the H_2O_2 method in our laboratory from two lung specimens of South African classical silicosis, obtained from the museum of the Pathology Department of Sheffield University, and further information was obtained on quartz contents of lung dusts isolated by various methods recently in South Africa (Talbot, 1959). The quartz percentages calculated by Robertson *et al.*

(1937) ranged from 46-66% of the total residues. These figures appear too high for the reason given above, and a range of 20-50% is more likely to be correct; this agrees with our own and recent South African *x*-ray diffraction analyses of residues prepared by H_2O_2 or other milder extraction methods. The chief constituent, apart from quartz, was the mica sericite. This mica occurs in the form of thin plates (Fig. 2). It had been described as fibrous previously (Jones, 1933) because plates on edge which look like fibres formed the bulk of the particles visible in canada balsam preparations under the polarizing microscope.

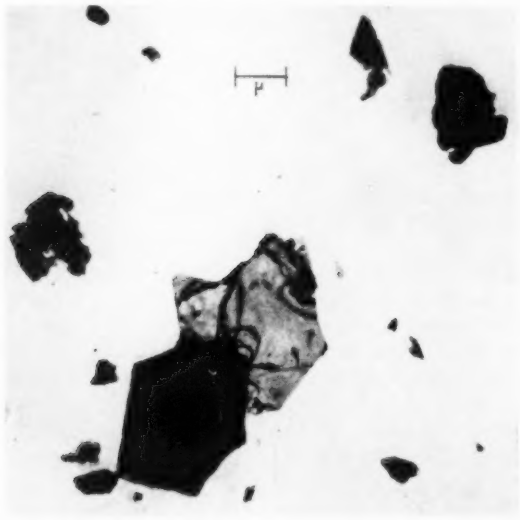


FIG. 2.—Sericite from lung dust of South African gold-miner with classical silicosis

AUSTRALIAN METAL MINERS AND TUNNEL WORKERS.—In a very valuable study Badham and Taylor (1938, 1941) gave the results of dust analyses of over 100 pneumoconiotic lungs, chiefly of coal-miners. These authors determined "free silica" by a chemical method, the "rational analysis" that had been developed in ceramic studies. Apart from determining total and free silica on samples of lung ash, they estimated "carbon" separately by alkali digestion of the tissues. They did not determine the total mineral residues. Their values for "free silica" may be 5-10% too low because the alkali treatment used to remove amorphous silica (resulting from decomposition of silicates by H_2SO_4) was rather drastic, but this effect is small and was ignored for our calculations. In order to obtain a value for the total mineral residue, their figures for "total combined silica" were doubled since many silicate minerals contain about 50% silica. This is a rough estimate, which would be approximately correct for mica, slightly high for felspar, and low in so far as free metal oxides may have been present in the lungs.

Badham and Taylor (1938, 1941) were chiefly interested in pneumoconiosis of coal-miners but amongst the lungs which they analysed were 26 in which the pathological description was that of silicosis, subdivided into moderate, marked, and massive. Their classification was as follows:

Moderate: Many fibrotic nodules, chiefly in the upper lobes, with or without small consolidations.

Marked: More numerous fibrotic nodules, especially in the upper lobes, with or without consolidations.

Massive: Fibrotic consolidations have largely taken the place of fibrotic nodulation.

A further subdivision of Badham and Taylor into "silicosis" (with more free than combined silica) and "siliceous type of pneumoconiosis" (with more combined than free silica) is based on the results of chemical analyses and not on histopathological observations, and for the present study their results for both groups were pooled.

TIN MINERS AND GRANITE WORKERS FROM CORNWALL.—This series of lungs was studied by King *et al.* (1956) in order to contrast with the lungs of coal-miners from South Wales. Mineral residues were prepared by low-temperature ashing and acid extraction, and were analysed by *x*-ray diffraction methods. Carbon in these lungs, determined by alkali digestion, was probably mainly soot or smoke from candles, acetylene lamps, and general air pollution.

Table 2 gives average values for the amounts of quartz, total minerals and, where possible, total dust including carbon, for various degrees of classical silicosis from the three above studies. The quartz content of the mineral portion and of the total lung dust has also been calculated.

In the series from South Africa the quartz percentage of the dust was assessed from the chemical analyses which had been carried out on all lungs with "very marked" fibrosis. The values ranged from 41-59% with a mean value of 48%. As only one lung dust with "marked" and none with "slight fibrosis" had been analysed an average value of 50% was assumed for these and is indicated by an asterisk (*) in Table 2.

From Table 2 it will be seen that in classical silicosis, about 1-3 g. of quartz in 4-8 g. of total dust were found in the lungs. On an average, lungs with massive fibrosis contained more dust (and more quartz) than lungs with early or moderate silicosis but each grade of fibrosis showed a considerable range of dust values.

In rapidly developing silicosis the exposure time to quartz-rich dust is of the order of months rather than years and the dust concentrations are very high. Simson and Strachan (1935) included a few such lungs in their series. They obtained about 6 g. of dust from single lungs of European gold-miners after 12 to 20 months of exposure and 13 and

TABLE 2

AVERAGE AMOUNT AND COMPOSITION OF LUNG DUST IN CLASSICAL SILICOSIS

Fibrosis	Number of Cases	Dust in Both Lungs			Quartz as percentage of Siliceous Minerals	Quartz as percentage of Total Dust	Occupation	Reference
		Quartz (g.)	Quartz and Silicates (g.)	Total Dust including Carbon (g.)				
Early to moderate	14	0·7	2·3	4·0	31	19	Tin miners and granite workers, Cornwall	King *et al.* (1956)
Slight	6	1·0*	2·1	ND	50*	ND	Gold-miners, South Africa	Simson and Strachan (1935)
Moderate	6	1·2	4·3	7·0	36	23	Metal miners and Sydney tunnel workers	Badham and Taylor (1938)
Marked	7	1·5*	3·1	ND	50*	ND	Gold-miners, South Africa	Simson and Strachan (1935)
Massive	20	2·6	5·9	7·4	49	33	Metal miners and Sydney tunnel workers	Badham and Taylor (1938)
Very marked	6	3·0	6·1	ND	48	ND	Gold-miners, South Africa	Simson and Strachan (1935)

* Indicates that quartz was assumed to be 50% of mineral dust, see text.
ND = not determined.

15 g. of dust from single lungs of natives with unknown exposure histories. The dust composition appears to have been the same as in classical silicosis, as for two of the dusts the calculated quartz percentages were 42 and 60%.

In two other cases of acute silicosis (Einbrodt, Graber, and Fitzek, 1957), the total lung dust, isolated by the formamide method, amounted only to 4 and 6 g. and the quartz present in the dust was of the order of 40%. It is not certain that the values refer to complete lungs.

To summarize, in classical silicosis from 1 to 3 g. of quartz and from 4 to 10 g. of total dust are found in the lungs with increasing degree of fibrosis. The quartz percentage of the dust may range from 20% upwards. The total dust present, expressed as a percentage of dried lung, is of the order of 1-4% and only rarely higher. In rapidly developing silicosis the quartz content of the lung dust is perhaps slightly higher, say above 30%, and the total amounts of dust may be considerably larger than in typical silicosis.

Pneumoconiosis of Coalworkers.—Pneumoconiosis of coalworkers has been studied extensively in many countries.

The first series of over 30 analyses of South Wales coal-miners' lungs, published by Cummins and Sladden (1930), cannot be used for our purpose because no distinction between free and total silica was made; this series appears to have included a high proportion of rock workers in coal-mines with silicotic lung changes. It is possible, however, to use the figures for total (ash-free) coal isolated by nitric acid digestion of the lung tissue. The amounts of coal present in both lungs ranged from 5 to 119 g. and the six highest values, for colliers and hard heading workers, were 119, 104, 97, 77, 52 and 37 g. coal.

Badham and Taylor (1938) analysed over 40 coal-miners' lungs from various coalfields in Australia. Their method has been described above and their data were evaluated in the same way as those of silicotic lungs, *i.e.* the weights of combined silica were doubled to give the amount of siliceous minerals other than quartz.

The pathological lung changes were classified by Badham and Taylor as follows:

Pneumoconiosis (Coal-dust Type)	Stage of Development	Lung Changes
Where the fibrosis presents the pathological appearance of perivascular fibrosis of coal-dust type, with nodulation or consolidation.	Early	Where perivascular fibrosis has developed; a little irregular fibrotic nodulation, chiefly in the upper lobes.
	Moderate	Where perivascular fibrosis has developed; irregular fibrotic nodules, chiefly in the upper lobes.
	Marked	Where perivascular fibrosis of all lobes has developed; irregular nodulation, with or without small consolidations.
	Massive	Where fibrotic consolidations have largely taken the place of perivascular nodulation.

The lungs analysed included nine cases described as massive, eight as marked and seven as moderate fibrosis. Mean values were calculated and are given in the upper part of Table 3.

Coal-mining and handling covers a variety of occupations; changes in the composition of the dust for different occupation groups are reflected in the composition of the dust recovered from the lungs. This has been shown by King and Nagelschmidt (1945) in a study of 54 lung residues of coalworkers from South Wales. The proportions of rock dust decreased from 75% of the total lung dust for rock

workers to 5% of the total dust for screen workers and trimmers. The largest group of men exposed to dust were colliers, and the lung dust found in colliers was intermediate in composition, containing on an average, 15% of rock dust (mainly mica and kaolin) and 2·2% of quartz.

In a later study (King *et al.*, 1956) whole lungs were analysed. The fibrosis of the lungs was assessed on the basis of the work of Belt and Ferris (1942):

Grade 2. *Dust reticulation:* a proliferation of reticulin fibrils, enclosing dust cells, of streaky distribution in the lung.

Grade 3. *Reticular and mixed nodulation:* focal indurations, rounded, angular, polygonal or stellate, composed of reticulin fibrils.

Grade 4. *Confluent fibrosis:* areas formed by the confluence of dust reticulation.

In this classification "reticular and mixed" nodulation is approximately equivalent to Badham's "moderate and marked" fibrosis and Belt's "confluent" to Badham's "massive" fibrosis. In the lower part of Table 3 average results are given of the lung dust analyses of colliers from South Wales. It will be seen that they are similar in composition to those of Badham and Taylor but that the amounts of dust found are higher. Amounts of dust exceeding 100 g. per pair of lungs as reported by Cummins and Sladden (1930) may be rare but they do occur. The largest amount of dust found in a collier from South Wales, who died at the age of 36, was 149 g. and Thomas (personal communication) isolated over 100 g. of dust from the lungs of a Ruhr coal-miner. The few published analyses of Ruhr lung dusts give the impression that the dust composition is variable but often similar to that found in Australia and South Wales.

As a general conclusion it appears that in the lungs of colliers with massive fibrosis there are on an average 40 to 50 g. of dust which contains over 80% coal; 10 to 15% of the dust is rock material and the quartz content of the lung dust is of the order of 2 to 3%. The total dust averages about 15% of the dried lung weight.

Thus the total amounts of dust are about 10 times higher than those found in classical silicosis but the amounts of quartz are lower. King *et al.* (1956) drew attention to the fact that the lungs of silicotic tin and granite workers contained on an average less quartz than the lungs of coalworkers with massive fibrosis. Tables 2 and 3 of the present paper show that this is no longer true when the more advanced cases of silicosis from South Africa and Australia are compared with the coalworkers.

Quartz-free Lung Dusts.—Most mineral dusts in mines, quarries, or factories contain quartz, which is one of the most widespread minerals in the crust of the earth. There are, however, cases where quartz forms less than 0·5% of the total dust and where the resulting fibrosis of the lung is unlikely to have been caused by quartz. Such dusts have been found by us in the lungs of men exposed to kaolin, talc, mica, and a mixture of coal and coke in electrode manufacture.

In most of these cases advanced pneumoconiosis with massive lesions had been found by radiological examination and several had been severely disabled. The pathological descriptions included widespread, macroscopically nodular, fibrosis without the fibrous hyaline lesions seen in silicosis, and superimposed were the grosser changes: dense collagenous masses in one or both lungs which contained large amounts of dust. Histological evidence of tuberculosis was sometimes present. Several of these cases of pneumoconioses still await publication by the pathologists concerned and no further histological description will therefore be given, but the similarities of the lung changes to those seen in massive fibrosis of coalworkers were described as close or striking.

Amounts and composition of dust found in these cases are given in Table 4. The average amount of

TABLE 3

AVERAGE AMOUNT AND COMPOSITION OF LUNG DUST IN PNEUMOCONIOSIS OF COAL-MINERS

Fibrosis	Number in Group	Dust in Both Lungs				Total Dust as percentage of Dried Lung	Quartz as percentage of Total Dust	Reference
		Coal (g.)	Quartz (g.)	Quartz and Silicates (g.)	Total dust (g.)			
Moderate	7	19·1	0·4	2·6	21·7	8·2	2·4	Australia (Badham and Taylor, 1938; 1941)
Marked	8	23·0	0·4	2·2	25·2	10·0	3·0	
Massive	9	32·3	0·7	5·0	37·3	15·6	1·8	
Dust reticulation	8	13·5	0·58	2·0	15·5	5·7	3·7	South Wales (King *et al.*, 1956)
Reticular and mixed nodulation	9	34·0	1·0	4·0	38·0	12·4	2·6	
Confluent fibrosis	10	49·2	1·2	5·0	54·2	14·7	2·2	

TABLE 4

AMOUNT AND COMPOSITION OF DUST IN LUNGS WHICH CONTAINED ALMOST NO QUARTZ

Case Number	Main Dust Constituent	Total Dust		Quartz as percentage of of Dried Lung	Death due to Pneumoconiosis	Reference
		Estimated* in Both Lungs (g.)	Percentage of Dried Lung			
1	Kaolin	96	26	Nil	Yes	Edenfield (unpublished)
2	Kaolin	ND	28	<0·05	Yes	Lynch and McIver (1954)
3	Kaolin	ND	26·5	<0·05	Yes	Lynch and McIver (1954)
4	Kaolin	50	35†	Nil	Yes	Hale, Gough, King, and Nagelschmidt (1956)
5	Talc	68	16·5	<0·05	?	Hunt (1956)
6	Talc and chlorite	58	14, 23‡	<0·02	Yes	Griffith (unpublished)
7	Talc and chlorite	45	13·2	<0·02	Yes	Griffith (unpublished)
8	Talc and kaolin	ND	10·0	<0·1	No	McLaughlin, Rogers, and Dunham (1949)
9	Muscovite	ND	12·0	0·01	No	Walker (unpublished)
10	Coke and coal	75	22·0	<0·02	Yes	Watson, Black, Doig, and Nagelschmidt (1959)
11	Coke and coal	100	34	<0·01	Yes	Watson *et al.* (1959)

* From dry weight of one or both lungs.
† On massive lesion.
‡ Values for right and left lungs respectively.
ND = Not determined.

dust was about 74 g. or 20% of dried lung weight, values which are even higher than those found in colliers with massive fibrosis. A lung dust analysis of a German electrode maker, very similar to Cases 10 and 11 in Table 4, has recently been described by Otto and Einbrodt (1958). They found about 90 g. of carbon in both lungs; the dust contained 3% total ash and approximately 0·1% quartz which could only be identified with difficulty by phase contrast microscopy on ashed lung sections after formamide treatment.

Lungs containing predominantly Iron Oxide.—For convenience, data on haematite miners and foundry workers are given together and one ochre lung is included.

HAEMATITE LUNGS.—The red lungs of haematite miners from Cumberland described and illustrated by Stewart and Faulds (1934) form a strong contrast to the black lungs of coal-miners. Chemical but no mineral analyses of the lung ash of such haematite miners were given by Faulds (1957).

One hundred and forty four fibrotic lungs with or without tuberculosis or carcinoma contained an average of 5% Fe_2O_3 and 1·2% SiO_2 as a percentage of dried lung. The average dried lung weight was about 400 g. From individual analyses given by Faulds and Stewart (1956) the estimated amounts of iron oxide per pair of lungs varied between 9 and 45 g.

Samples of some 70 of these lungs are being analysed in our laboratory but this work is not yet complete. The average lung dust composition is approximately 80% haematite, 5% quartz, and 15% mica. The estimated amounts of dust found in the lungs with massive fibrosis classed as +++ range from 30 to 85 g. This, as well as the histological descriptions, suggests that the disease is more similar to pneumoconiosis of coal-miners than to classical silicosis although the quartz percentage of the lung dust is about two to three times as high as that of coal-miners.

In contrast to these observations, Gerstel (1941) found that the total iron oxide (Fe_2O_3) in the lungs of silicotic coal-miners, lead-, and zinc-miners, and ceramic workers ranged between 0·4 and 5 g.; he found similar values for silicotic iron-ore-miners from the Siegerland. He concluded from his observations that inhaled iron oxide was capable of being excreted from the lungs. It is not likely that inhaled haematite is removed at a greater rate from the lungs than coal, quartz, or kaolin and it is more likely either that the airborne dust in the Siegerland mines did not contain much iron oxide or that Gerstel failed to analyse lungs which had accumulated it.

FOUNDRY WORKERS.—The fibrotic lung changes of foundry workers range from classical silicosis to what Harding, Gloyne, and McLaughlin (1950) describe as "mixed dust pneumoconiosis": "a perivascular and peribronchial fibrosis consisting of collagen, reticulin, dust and cells, growing into large irregular patches in the later stages of the disease but without the sharply defined whorled nodule of classical silicosis. . . . The picture at times resembles that in South Wales coalworkers". In a later paper, McLaughlin and Harding (1956) gave average values for total and free silica, the latter determined by a chemical method (Trostel and Wynne, 1940) for 65 lungs of foundry workers, classified into four stages of fibrosis, *viz.*, massive, nodular, minimal, and nil. Unpublished figures for

total iron oxide for these lungs were obtained from Dr. H. E. Harding, and by doubling the values for combined silica, approximate values for total mineral dust (minus carbon) and for the quartz percentage of this dust were obtained. These figures are given in Table 5. In massive fibrosis the total dust was 2·6% of dried lung and even if one assumes a high average dry weight of 400 g. for these lungs, the total dust would only be about 11 g. Quartz in the lung dust, however, was 15%. These values suggest that the disease of foundry workers in these cases may have been more similar to classical silicosis than to the pneumoconiosis of haematite miners.

The lungs of a fettler (X5371) who had worked for 28 years in an iron foundry and lived for eight years after the end of his dust exposure were analysed in our laboratory. His lung fibrosis was, according to Dr. H. E. Harding, who supplied the material, intermediate between classical silicosis and mixed dust fibrosis. The lung dust contained 45% quartz and 15% cristobalite, the balance being made up of iron oxides, mainly haematite. The total dust was 7·4% of dried lung and amounted to about 15 g. in both lungs. According to animal experiments cristobalite is slightly more fibrogenic than quartz. It can be formed by the interaction of molten iron with fine-grained quartz or clay and has also been found by us in foundry dusts. The figure for free silica as a percentage of dried lung in this case was over three times higher than the highest value found by McLaughlin and Harding (1956), and the pathological picture of classical silicosis might have been expected on the basis of the lung dust analysis.

OCHRE.—As a contrast the case of an ochre grinder (X5700) may be mentioned who had worked at or near a pigment mill grinding iron oxides and hydroxides. He had been exposed to this dust for over 40 years and had died at the age of 66, seven years after ending his dust exposure. According to Dr. H. E. Harding his illness and death were unrelated to the dust exposure. The lungs showed "focal red pigmentation associated with doubtful focal emphysema and there was definite but not severe fibrosis of mixed dust type". The lung dust consisted of 70% iron oxide and hydroxide, about 20% kaolin, with some mica, and 10% carbonaceous material. There was less than 1% of quartz in the dust. The total dust amounted to 10% of dried lung or about 17 g. in both lungs. This man had more dust in his lungs than the iron fettler (X5371) and far more than any of McLaughlin's and Harding's (1956) foundry workers with massive fibrosis; in the absence of quartz, the fibrosis was not severe. This case is also interesting because it suggests that Harding's "mixed dust pneumoconiosis" may arise in the almost complete absence of quartz.

The quartz content of the lung dust seems to increase in the order ochre worker, haematite miners, foundry workers; the silicotic features of the fibrosis appear to follow the same trend.

Berylliosis, Aluminosis, Shaver's Disease, and Asbestosis.—These forms of pneumoconiosis are grouped together because the fibrosis is described as interstitial rather than nodular, although the chronic fibrosis in berylliosis also shows granulomata. Aluminosis and Shaver's disease have a further similarity in the frequent occurrence of spontaneous pneumothorax.

BERYLLIOSIS.—The amounts of beryllium found by spectrographic analyses of lung ash in a few cases of chronic berylliosis were of the order of 20 μg. per 100 g. wet lung (Machle, Beyer, and Tebrock, 1949), and for one case they were given as 0·16 mg. for the whole lung (Martland, 1950). There are very few analyses published, but they suggest that 1 mg. of beryllium oxide may be the upper limit for the total amount of dust found in the lungs in chronic berylliosis.

ALUMINOSIS.—Unfortunately, no data exist for the various cases of aluminosis reported from Germany by Goralewski (1950) except that aluminium could be demonstrated in the lungs by fluorescence microscopy. In one case, recently reported from Britain (Mitchell, 1959), where there was extensive diffuse fibrosis of the lungs, the average aluminium content of the dried lung was given as 0·03%. The total weight of the lungs had not been recorded but even assuming it to have been 400 g., the total dust would only be 120 mg. of aluminium (Al) or 250 mg. of alumina (Al_2O_3) in both lungs.

TABLE 5

AVERAGE AMOUNT AND COMPOSITION OF DUST IN FOUNDRY WORKERS' LUNGS (MCLAUGHLIN AND HARDING, 1956)

Fibrosis	No. of Lungs	Percentage of Dried Lung				Quartz as percentage of Total Dust
		Fe_2O_3	Quartz	Silicates	Total Dust*	
Nil	9	0·80	0·10	0·22	1·1	9
Minimal	26	0·70	0·22	0·54	1·5	15
Nodular	18	1·05	0·31	0·68	2·0	15
Massive	11	1·2	0·38	1·0	2·6	15

* Excluding carbon.

SHAVER'S DISEASE.—Jephcott (1948) has given analyses of the ash of six cases of Shaver's disease. The lung dust was similar to the fume which consisted mainly of spherical particles of amorphous alumina and silica, with minor amounts of α and γ-Al_2O_3.

The average alumina content was 1·95% and the average silica 1·61% of dried lung. As these two oxides were the main fume or dust constituents, the total lung dust was of the order of 3·6% of dried lung (with a range of 2-4·9%). There was no clear relation between the amount of dust and length of dust exposure although the case with the longest exposure had the lowest amount of dust. No data exist by which a relation between the amount of dust and the severity of fibrosis can be assessed.

ASBESTOSIS.—Lung dust analyses in asbestosis are surprisingly rare. Sundius and Bygdén (1937) gave a very detailed account of the lung dust analysis of one case of asbestosis. They estimated the total mineral dust in both lungs as 2·8 g., half of it being hornblende asbestos, the remainder rutile, quartz, and carbonates.

More extensive data were given by Knox and Beattie (1954) who ashed representative portions of both lungs from 27 cases and extracted the ash with dilute hydrochloric acid. They found, on an average, that the mineral dust amounted to 0·4% of dried lung without any clear increase in the amount of dust with increasing severity of fibrosis, but with a decrease in dust in proportion to the period between the end of dust exposure and death. Hilum and pleura contained as much as, or more, dust than the lungs on a percentage basis.

With an assumed dry weight of 300 to 400 g. for lungs, hilum, and pleura, the total amounts of dust found by Knox and Beattie (1954) would be of the order of 1·5 to 3 g., in good agreement with the data of Sundius and Bygdén (1937).

A lung dust analysis of a case of severe asbestosis (X5747) (given to us by Dr. D. Rivers of the Pneumoconiosis Research Unit) carried out recently in our laboratory showed very little dust corresponding to 0·8% dried lung, or 1·3 g. in the right lung, but no asbestos mineral could be identified by *x*-ray diffraction nor could fibres be seen by optical or electron microscopy in the isolated lung dust.

Asbestos is a general term which covers chrysotile ($Mg_3Si_2O_5(OH)_4$) and several hornblende varieties. As far as we know, no positive identification of chrystotile in a human lung with asbestosis has so far been published, and more information on the amount and composition of the lung dust in asbestosis is needed.

Discussion

It has been shown in the preceding section that severe disabling fibrosis of the lungs is associated with dusts of different composition and in different amounts. At one end of the scale, in chronic berylliosis, there may be only 1 mg. or less of beryllium in the lungs; at the other end of the scale there may be over 100 g. of dust with little or no quartz.

When a man is breathing dusty air, a certain proportion of dust particles, depending on their aerodynamic "size", penetrate the upper respiratory tract and are deposited in the deeper parts of the lung. This initial deposition varies with the size of dust and breathing rate and is amenable to calculation (Findeisen, 1935) and experiment (Altshuler, Yarmus, Palmes, and Nelson, 1957; Dautrebande, Beckmann, and Walkenhorst, 1957; 1958). But dust deposition is followed by dust clearance, mainly by migration of dust-laden phagocytes up the bronchial tree, and to some extent by transport to the lymph glands. Accumulation of dust in the lungs only takes place in so far as these two defense mechanisms are insufficient, and it will depend further on the rate at which the dust can be dissolved.

Soluble Dusts.—Dusts appear to be completely insoluble or more or less soluble inside dust cells or in tissue fluids. Test tube experiments give only limited guidance on this point because the rate at which the dissolving fluid extracts the dust deposit, the diffusion rate of the dissolving components, and even the *p*H at which the reaction takes place, are unknown. Animal experiments are intended to bridge this gap, but their value is somewhat limited on account of the short lifespan of the smaller animals generally used. Outstanding examples of slightly soluble dusts which apparently do not cause pneumoconiosis in men, in spite of heavy dust exposure histories, are calcite (Bridge Davis and Nagelschmidt, 1956) and gypsum and cement (Sander, 1958). Impurities in calcite and gypsum and the raw material used in cement manufacture can, however, cause pneumoconiosis (Doig, 1955; Doerr, 1952).

But it appears likely that certain slowly dissolving constituents can cause a particular type of fibrosis which is neither focal nor nodular and is usually described as disseminated or interstitial. Such interstitial fibrosis is the common factor in berylliosis, aluminosis, Shaver's disease, and asbestosis. From the point of view of the lung dust analysis, the following appear to be criteria for soluble dusts:

(1) An obvious disproportion between the amount of

dust and the amount of fibrosis (suggested by the figures for berylliosis and aluminosis).

(2) A gross lack of parallelism between the amount of dust and the degree of tissue change for a given type of dust.

(3) An obvious decrease in the amount or size of dust with an increasing length of time between the end of dust exposure and death.

(4) Differences in composition between airborne dust and lung dust.

The data of Knox and Beattie (1954) suggest that Nos. 2 and 3 above are present in asbestosis; there is also limited evidence for No. 4, as the bulk of asbestos dust in manufacture is chrysotile but no chrysotile has been found in the few asbestosis lungs which have been examined mineralogically.* Present information is clearly insufficient but there are grounds for supposing that the breakdown products of chrysotile and hornblende may cause the interstitial fibrosis of mainly the lower lobes which characterizes asbestosis, rather than the mechanical damage by the larger fibres, which is at present believed to be its cause. If this were true, the silicic acid rather than the magnesium hydroxide released in the breakdown of chrysotile or hornblende would be likely to cause this fibrosis. It also appears possible that in aluminosis and in Shaver's disease dust solubility plays a role, and that aluminium ions and polysilicic acid dissolving from the silica fume in Shaver's disease, precipitate proteins and cause the fibrosis which is, as in asbestosis, interstitial rather than nodular. Aluminosis and Shaver's disease were mainly produced under abnormal dust conditions during the second world war and they appear at present to be rare. Arc furnace fumes in alloy or abrasive manufacture or in other industries may, however, still cause this form of disease.

The correlation of slow solubility of certain dusts and the appearance of diffuse interstitial fibrosis is at present hardly more than a speculation based on the scanty data given above. More lung dust analyses are required before it can be accepted as correct and it should also be supported by physico-chemical studies and animal experiments. In contrast, the data for insoluble dusts are far more copious.

Insoluble Dusts.—If the lung dust has approximately the same composition as the airborne dust of similar size and if increasing severity of fibrosis corresponds to increasing amounts of dust, irrespective of the length of period between the end of dust exposure and death, then it is likely that the fibrosis is due to the continued presence of the dust itself rather than to the effects of a dissolving constituent or of its residue. This appears to be the case in classical silicosis, in the pneumoconiosis caused by quartz-free dusts, and in the diseases intermediate between them such as coalworkers' and haematite miners' pneumoconiosis. Quartz has a specific capacity to cause excessive formation of collagen which is not due to its limited initial solubility (Englebrecht, Yoganathan, King, and Nagelschmidt, 1958; Marks and Nagelschmidt, 1959) and it is tempting to relate this extra fibrogenic power of quartz to the smaller amounts of dust found in classical silicosis and to conclude that, on average, the higher the quartz percentage the lower the total amount of dust collected in the lungs before disability makes an end to further uptake of dust.

In Fig. 3 the average amount of quartz in lungs with massive fibrosis is plotted against the average amount of total dust for gold-miners with classical silicosis, for coal-miners, and for the quartz-free lung dusts. Further areas are also given for foundry workers and haematite miners. It may be an accident that the three areas for the first group lie on a straight line, but the general trend is probably not accidental. The broken line separates on the left the field in which quartz is above 18% of the total dust, as is almost invariably found in classical silicosis, and on the right the field where quartz is less than 18% of the total dust. It would seem obvious that there cannot be such a sharp boundary but the further one moves away from it to the right, the more does the lung pathology, in the parts in which there are no massive lesions, depart from collagenous nodules and the more does it approach that of simple pneumoconiosis as described for instance by Heppleston (1947). The existence of the boundary can perhaps be explained by assuming that the stimulus to the excessive collagen formation requires a quartz concentration inside phagocytes which is not reached if the quartz percentage of the dust falls too low. The position of the area for haematite miners may suggest a partial inhibition of the fibrogenic activity of quartz by iron oxide.

The data given in Tables 2 to 5 demonstrate that, on average, the amounts of dust and the severity of tissue changes in lungs are well correlated for insoluble dusts. How this can be reconciled with the conception that classical silicosis and most forms of massive fibrosis are progressive in the sense that a given amount of dust will go on producing more and more collagen or increasing areas of massive fibrosis as time goes on can probably be explained by two factors; the usually slow development of the disease, and the selection of lungs that become available for

* Knox and Beattie (1960) have recently observed the presence of chrysotile in asbestosis bodies obtained from human lungs. (Symposium on Inhaled Particles and Vapours, Oxford, March 29 to April 1 .1960.

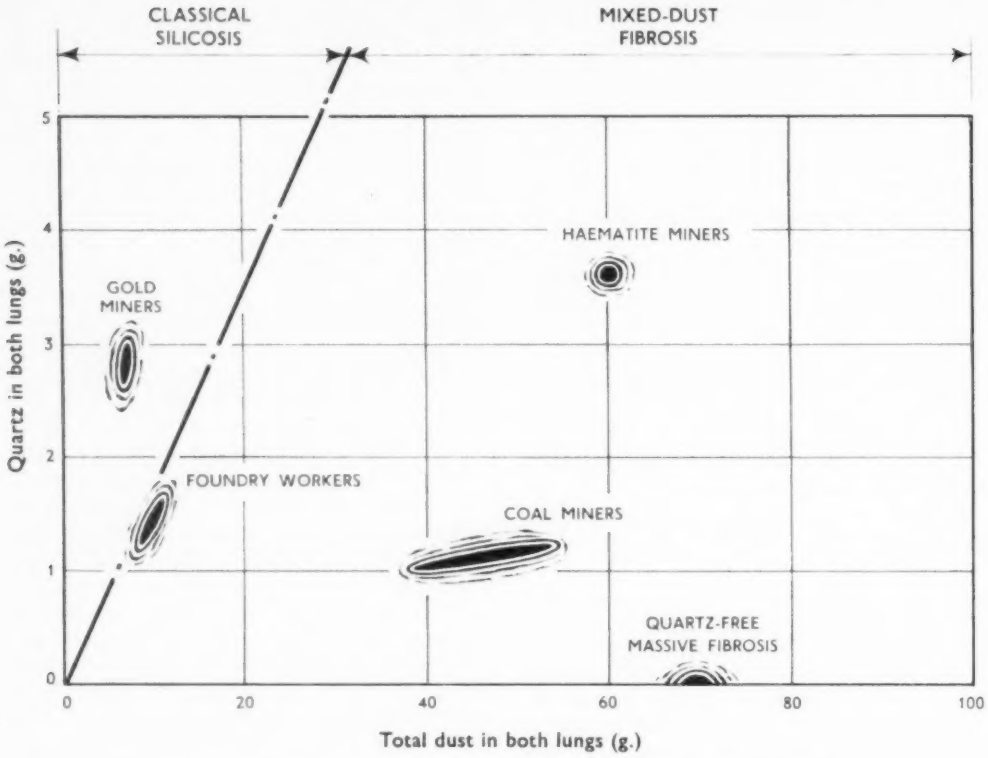


FIG. 3.—Average values of total dust and quartz in lungs with advanced forms of different dust diseases.

study. Cases of classical silicosis with negligible amounts of fibrosis in the presence of large amounts of dust are unlikely to be found because the uptake of dust is usually so slow that the development of fibrosis keeps pace with it; and in any case such cases would not become available for analysis until fibrosis had developed sufficiently to cause death. It is only in the so-called "acute" or rapidly developing silicosis that a disproportion between dust and fibrosis might occur.

Similar considerations apply to the massive fibrosis (PMF) of coal-miners. This is believed to be the result of an infective process, probably mainly tuberculosis, in a dust-ridden lung, and is believed not to require any further uptake of dust. As the chances of development of PMF are higher the more advanced the simple pneumoconiosis is (Cochrane and Miall, 1956), it is not surprising that in an earlier study (King *et al.*, 1956), more dust on average, was found in the lungs of coal-miners with PMF than in lungs with the most advanced type of simple pneumoconiosis (see Table 3).

However, recent work based partly on lung dust analyses of coal-miners, killed in accidents, who had been examined radiologically two years or less before death, showed, on average, for radiological stage 3 of simple pneumoconiosis, 53 g. of total dust in both lungs, with four cases out of nine ranging from 60 to 88 g. (Rivers, Wise, King, and Nagelschmidt, 1960).

Amongst 15 further pit accidents there were four more cases of simple pneumoconiosis which had between 25 and 65 g. of dust. Unless special efforts had been made to obtain such accident cases which may be considered as a random selection of coal-workers, similar lungs would probably not have been analysed until PMF had developed and had caused or contributed to their death.

Mixed Dusts.—In the foregoing, a distinction has been drawn between soluble dusts which cause interstitial, and insoluble dusts, which cause nodular fibrosis of the lungs. Mixed forms have been described especially in diatomite workers, where the dust, and the lung residues, consist of a mixture of quartz and sometimes cristobalite, and much amorphous silica (Löblich, 1958). It is possible that polysilicic acid resulting from the dissolution

of the amorphous silica causes the interstitial, and quartz and cristobalite the nodular fibrosis in these lungs. This again requires support by further laboratory studies.

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DIFFUSE PLEURAL MESOTHELIOMA AND ASBESTOS EXPOSURE IN THE NORTH WESTERN CAPE PROVINCE

BY

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Primary malignant tumours of the pleura are uncommon. Thirty-three cases (22 males, 11 females, ages 31 to 68) of diffuse pleural mesothelioma are described; all but one have a probable exposure to crocidolite asbestos (Cape blue). In a majority this exposure was in the Asbestos Hills which lie to the west of Kimberley in the north west of Cape Province. The tumour is rarely seen elsewhere in South Africa.

Mesothelioma of the pleura is regarded as an uncommon tumour. In the last four years we have seen 33 histologically proven cases; 28 of these had some association with the Cape asbestos field and four cases had been exposed to asbestos in industry.

The tumour is rarely encountered elsewhere in South Africa. During the past five years, with the exception of the present series, no neoplasm of this nature has been diagnosed amongst 10,000 lungs examined at the Pneumoconiosis Bureau in Johannesburg, or in the Pathology Department of the South African Institute for Medical Research. Higginson and Oettle (1957) did not observe a single case in their survey of malignant tumours occurring in the Bantu and Cape Coloured population of Johannesburg and the North Eastern Transvaal.

Our first necropsy specimen of pleural mesothelioma with asbestosis was examined at the Pneumoconiosis Research Unit in February, 1956 (Case 1). During the early months of that year, one of us (C.A.S.) in the Northern Cape, treated six patients with gross pleural thickening. Pleural biopsies from two of them showed the features of mesothelioma. In the ensuing two years, eight further cases were found from this region and five from elsewhere in the Union. During this period C.A.S. had become perturbed at the number of these unusual tumours occurring amongst his patients, and stimulated an investigation. At this stage there were two reasons to suggest that asbestos might be implicated. First, asbestos was found in the lungs of the first case (Case 1), and secondly, 10 of the cases came from a hospital to which suspected cases of tuberculosis were referred from a large asbestos mining area. This hypothesis could not be supported at once from the original histories obtained from the patients, for they included housewives, domestic servants, cattle herders, farmers, a water bailiff, an insurance agent, and an accountant, none of whom were working on the asbestos mines at the time. We therefore undertook a detailed investigation of their past occupation and place of residence, and the association with asbestos exposure was discovered. The cases are summarized in Table 3. Previous biopsy specimens were re-examined, and new cases diagnosed, including asbestos miners. In only one case do the relatives deny that the patient either visited the asbestos mines or was exposed to asbestos.

This is a preliminary publication and the problem is being intensively investigated.

The Asbestos Area of the North-West Cape

According to Hall (1930) asbestos was discovered by Lichenstein near Prieska during his travels between 1803 and 1806. Since then it has been established that the asbestos deposits extend from 20 miles south of Prieska, northwards through the western part of the magisterial district of Hay, to the eastern portion of the magisterial district of Postmasburg and finally, to the western area of the

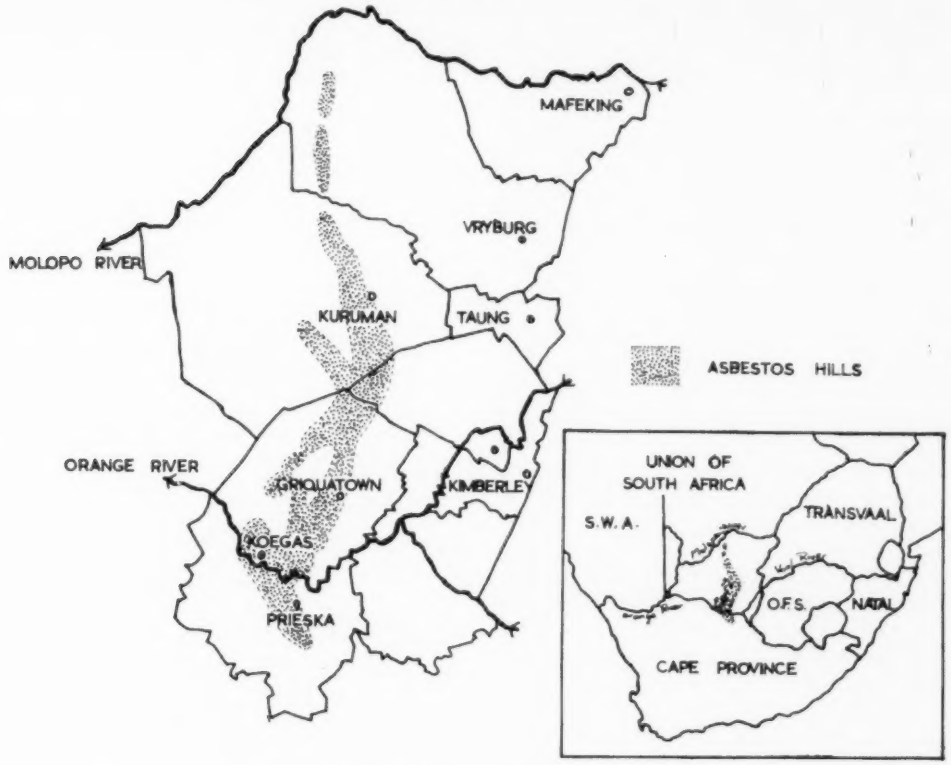

FIG. 1.—Map of Griqualand West asbestos fields.

district of Kuruman (Fig. 1). These deposits occur in the slopes of a range of hills covering an area of approximately 8,000 square miles. Known as the "Asbestos Mountains", these hills extend more or less longitudinally between 22·30° and 23° E. The whole area is semi-arid, sparsely populated, and, apart from mining, cattle ranching is the only important occupation. In the Kuruman area several large tracts of land in or abutting on these mountains have been reserved for the aboriginal inhabitants and here whites may only reside in the immediate vicinity of the mines.

The type of asbestos mined throughout this area is crocidolite, better known as Cape Blue Asbestos. The chemical analysis of the fibre is given in Table 1. Crocidolite is the fibrous form of riebeckite and all stages of transformation from a massive riebeckite rock through lamellar riebeckite to asbestiform crocidolite occur in this region. Magnetite is frequently associated with the crocidolite (Vermaas, 1952).

Mining of asbestos first began in the Prieska district in 1893 and gradually spread northwards. In 1908 production had begun in the Kuruman district. Between 1916 and 1918 a large number of claims were taken up. This northward trend has continued and in about 1950 mining started at Pomfret near the Bechuanaland border (Table 2).

Initially the ore was quarried in numerous small open cast workings. This was followed gradually

TABLE 1

CHEMICAL ANALYSES OF CROCIDOLITE AND AMOSITE
(from Vermaas, 1952).

	Crocidolite	Amosite
SiO_2	51·94	49·47
Al_2O_3	0·20	0·63
Fe_2O_3	18·64	4·15
FeO	19·39	35·63
MgO	1·37	6·57
CaO	0·19	0·52
Na_2O	6·07	0·02
K_2O	0·04	0·20
H_2O-	0·31	0·07
H_2O+	2·58	2·33
TiO_2	—	0·25
MnO	—	0·61
F	—	0·01
Total	100·73	100·46

TABLE 2

POPULATION OF THE MAGISTERIAL DISTRICTS IN WHICH THE ASBESTOS FIELDS ARE SITUATED
(taken from Union Census 1921, and 1951)

District	Population 1921			Population 1951		
	Whites	Non-whites	Total	Whites	Non-whites	Total
Prieska	3,430	4,879	8,309	3,361	10,847	14,208
Kuruman	4,713	16,698	21,411	4,818	23,779	28,597
Hay	4,499	8,814	13,313	2,757	9,631	12,388
Postmasburg	Included in the Hay District			4,887	21,019	25,906

by a type of shallow mining; inclined shafting became more common after 1930.

According to Frood (1915), the quarrying was a family affair undertaken by the local inhabitants. The men quarried the rock, which was sorted and then hand cobbed by the women and children. Hand cobbing consists of separating the fibre from the banded ironstone by striking the rock cob with a small hammer. As the market was selective, a rotary sieve was sometimes used to grade the fibre and eliminate the small particles of dust. After grading, it was bagged and weighed. The asbestos was then transported by donkey wagon to the nearest rail-head. Before the establishment of the railway in this area between 1923 and 1930, such a journey could last as long as 10 days. This transport was generally undertaken by white youths (farmers' sons) under contract. The white inhabitants played very little part in actual recovery of the fibre, being nearly always employed in the role of managers or overseers, issuing stores and supervising the grading and weighing of the fibres. Farming activities were and are still carried out round the mines.

Since the 1939-1945 war, the demand for crocidolite has enormously increased. The lucrative claims have been bought by registered companies, others have been abandoned. As deeper and richer deposits have been found, vertical shafts are being sunk. However, the mines with large shallow deposits are still using the inclined shaft and tunnel, and quarrying is still used by the few remaining smaller producers. With the building of more mills, hand cobbing has diminished. In 1915 the first crushing mill was established at Koegas in the south. This was followed by a large mill at Kuruman (operated between 1926 and 1931) where it was situated within 300 yards of the main street, close to which cobbing was also done for a few years (1927-1930). This was followed by a mill at Prieska in 1930, which was completely rebuilt in 1957. Griquatown had a small mill in 1928. The practice today is for one mill to serve several mines in the immediate vicinity.

In the early days the manager and labourers lived within a few yards of their place of work, and even today the non-white prefers to live as close as possible, and the children play on the dumps from the mine and mill.

Case Histories

The following eight case histories illustrate various aspects of the disease and the different types of exposure to asbestos dust.

Case 1.—B.P., a Bantu male, 36 years of age (born 1920), was a mine labourer, and was the first case diagnosed as a mesothelioma with evidence of asbestosis. He was born in the Kuruman district but it is not known whether he worked in the asbestos mines. He was employed on the Witwatersrand gold-mines underground for two years and in the change rooms for a further 11 years.

A radiograph taken at a mine hospital on August 18, 1955 showed a massive right-sided pleural effusion, and 3,000 ml. of fluid was withdrawn. He was admitted to the Witwatersrand Native Labour Association Hospital on August 24, 1955, and two days later aspiration yielded 1,000 ml. of thick gelatinous pus "which could be pulled out in threads". He was treated with frequent aspirations and instillation of varidase but without improvement, and he died on February 15, 1956 (Martiny, 1956).

At autopsy the right thoracic cavity was occupied by a large gelatinous tumour which displaced the mediastinum and compressed the left lung. The tumour had infiltrated the pericardium. The right lung was completely compressed by neoplastic tissue (Fig. 2) but the right bronchial tree did not show any evidence of a primary bronchogenic carcinoma. Histological sections of the pleural growth showed a papillary mesothelioma (Fig. 3). There was evidence of asbestosis in both lungs (Fig. 4).

Case 4.—K.H., a white female, 56 years of age (born 1898), was a social worker, who could only have had a short exposure to asbestos as a child and probably a further slight exposure as a young woman. She may have paid several short visits to the mines with her husband at a later period.

She was born in Griquatown where she lived until she was 5 years of age. Her family then moved to Kimberley where from 1916 to 1922 she worked as a clerk in an asbestos warehouse. Her husband owned an asbestos mine from 1933-1940.

FIG. 2

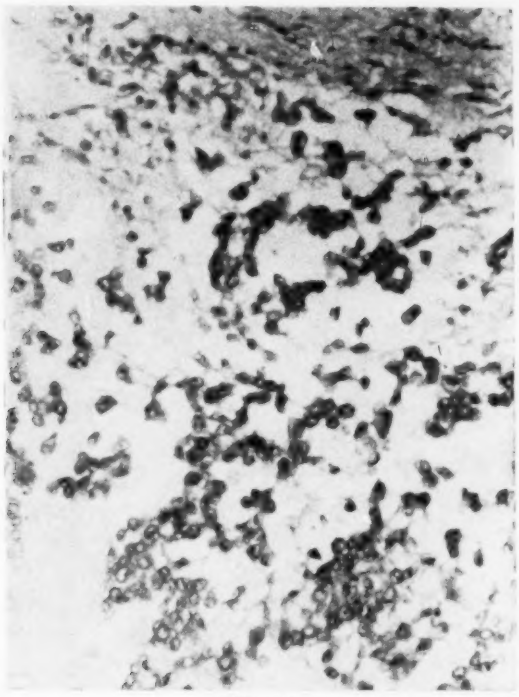

FIG. 3

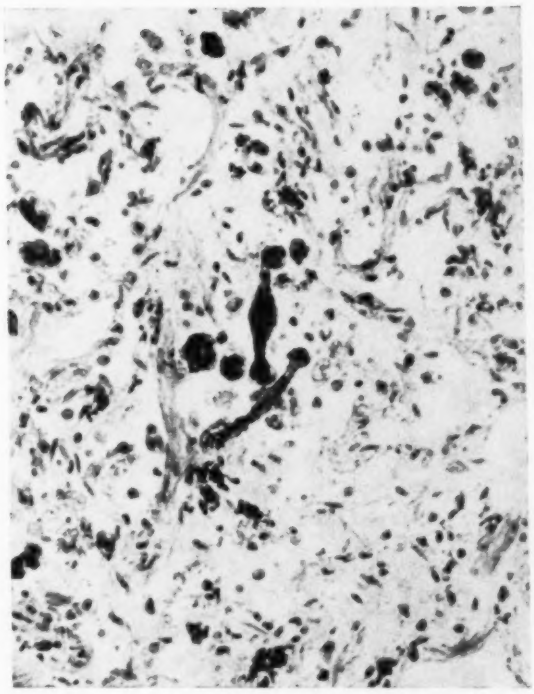

FIG. 4

FIG. 2.—Right lung of Case 1 showing a tumour compressing the lung substance.

FIG. 3.—Cellular structure of tumour of Case 1. × 40 Haematoxylin and eosin.

FIG. 4.—Sections of lung from Case 1 showing asbestos bodies. × 40 Haematoxylin and eosin.

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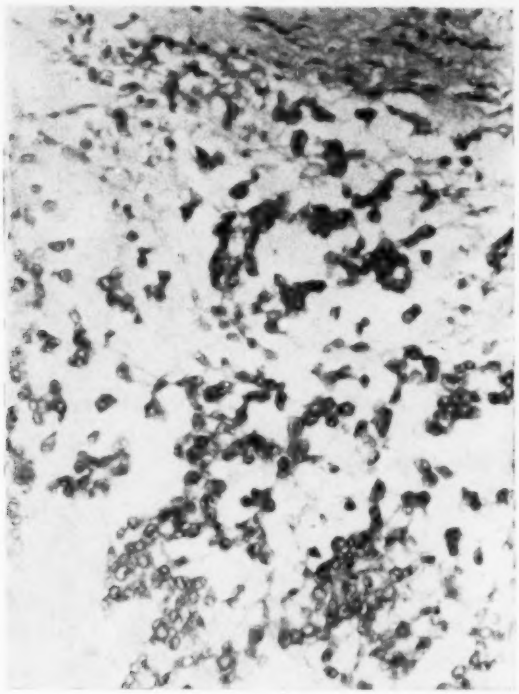
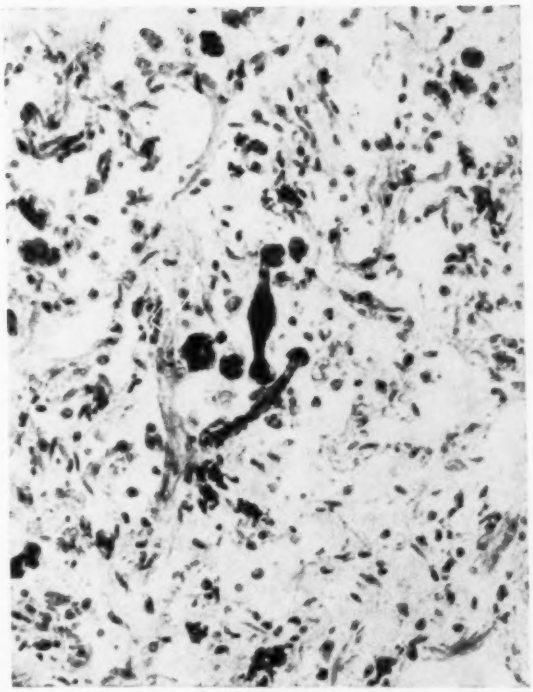


FIG. 3



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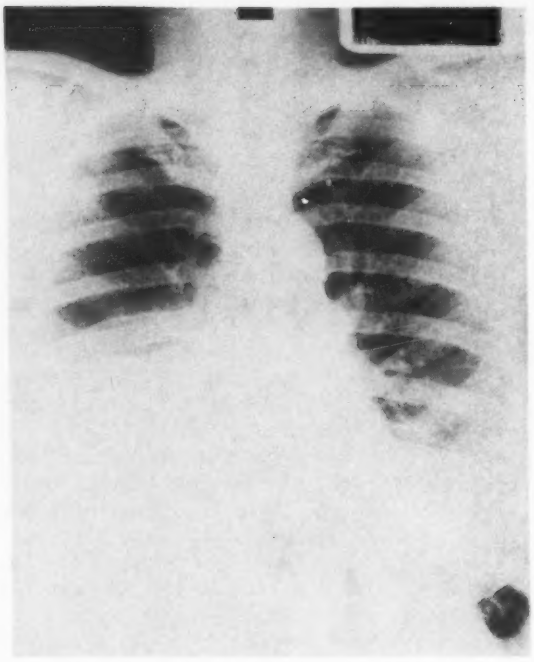

FIG. 5.—On July 21, 1954.

FIG. 6.—On July 7, 1955.

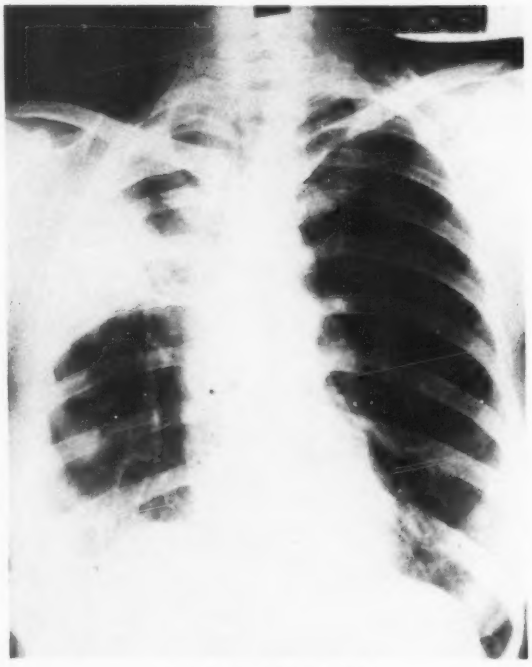

FIG. 7.—On March 3, 1956.

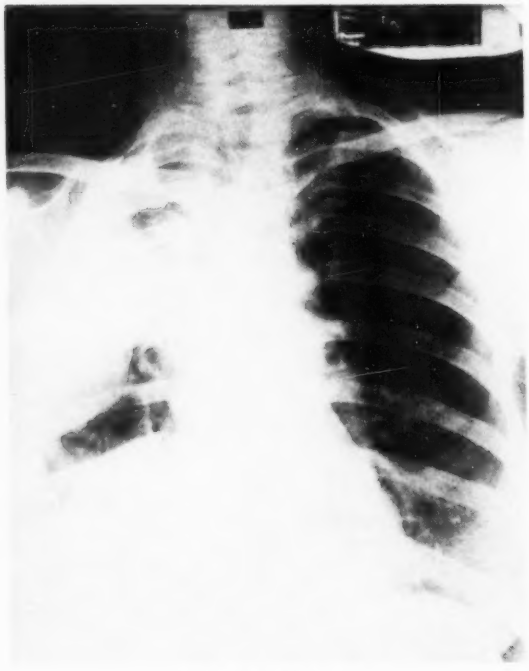

FIG. 8.—On July 3, 1956

FIGS. 5, 6, 7, and 8.—Radiographs showing development of tumour in Case 4.

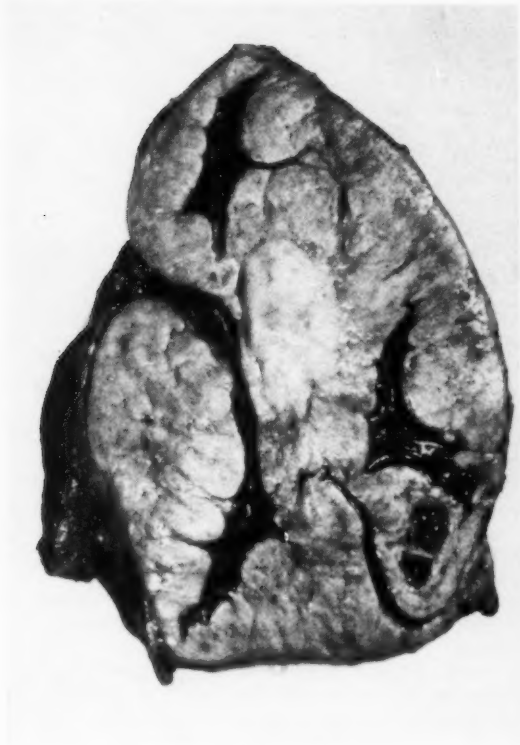

FIG. 9.—Right lung of Case 14.

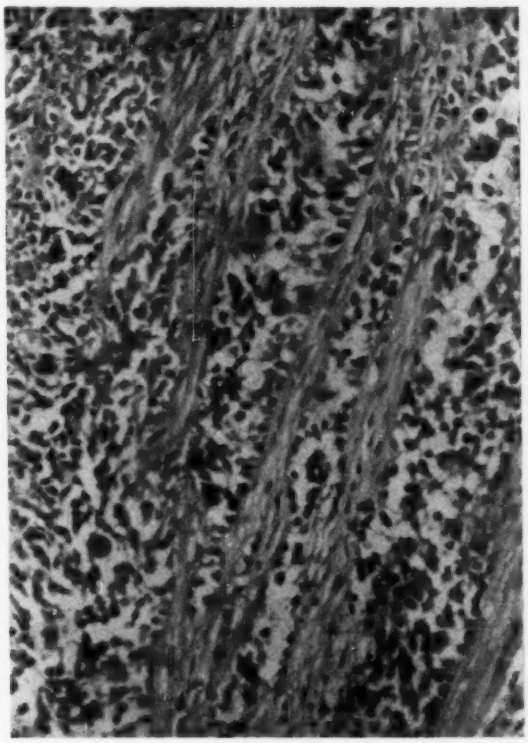

FIG. 10.—Histological sections of tumour from Case 14. × 24 Haematoxylin and eosin.

She was referred to the West End Hospital, Kimberley, on July 19, 1954, because of dyspnoea and right chest discomfort of acute onset. The chest radiograph showed a loculated pleural effusion at the right base. Straw-coloured fluid was aspirated, which on examination was found to be negative for *M. tuberculosis* but contained mesothelial cells arranged in acini. At thoracoscopy in Johannesburg on August 11, 1954 tumour nodules were seen on the parietal pleura. Histological examination of the biopsy specimen showed a mesothelioma. Deep therapy and radio-active gold instillation in September, 1955 caused initial regression of both the pleural fluid and nodules but did not arrest the progress of the disease. She received a further course of *x*-ray therapy without improvement and died in January, 1957. The liver was enlarged and nodular before death but no necropsy was done. (Figs. 5, 6, 7, and 8 show the radiological development of the tumour in this case.)

Case 14.—S.S., a Bantu male, 40 years of age (born 1918), was an asbestos miner. He was born in the Kuruman district and as a child often played on the asbestos dump near an asbestos mine. He subsequently worked with asbestos for several years, being employed at an asbestos mine weighing fibre from 1938-41. In 1942 he worked on a Witwatersrand gold mine but returned to the Kuruman district in 1943 where he worked as a farm labourer until his final illness.

He was admitted to the West End Hospital on March 3, 1959. He had been well until July, 1958 when he became aware of pains in the right side of his chest. In addition he had a slightly productive cough and shortness of breath on exertion. Chest radiograph on March 9, 1959 showed obliteration of the right lung field. Asbestos bodies were found in the sputum. Needle biopsy showed histological features consistent with a mesothelioma.

AUTOPSY.—The right chest was occupied by a huge whitish tumour which infiltrated the mediastinum, extending through the diaphragm onto the superior surface of the liver. A straw-coloured effusion was present in the left pleural sac but the left lung was not affected. The mediastinal, cervical, and para-aortic abdominal lymph glands to the level of the renal arteries were infiltrated with tumour.

In the right lung it was found that the tumour mass had infiltrated along the interlobar fissures. The lobes of the lung were compressed into three small segments (Fig. 9). On histological section a papillary type of pleural mesothelioma was seen (Fig. 10) which had infiltrated into the lung parenchyma in some areas. There was marked lymphatic spread throughout the

lung substance. Numerous asbestos bodies were present in the air spaces and occasional bodies and fibres were seen in the interstitial tissue. The lung itself was markedly atelectatic. Evidence of asbestosis was observed in the left lung.

Case 15.—S.S.V., a white female, 42 years of age (born 1916), is a housewife, who lived on a mine near Johannesburg and was treated for tuberculous pleurisy for six months. It was only after the histological diagnosis of a mesothelioma had been made that her previous history was obtained. In addition, it was subsequently learnt that her father (Case 22) had been born on the asbestos field and had a long mining history.

The patient was born in the Griquatown district and went to school at Kuruman. She spent most of her youth in the asbestos belt. She has lived near Johannesburg for 20 years.

In March, 1958 this patient developed right chest pain and rapidly increasing shortness of breath. She was admitted to hospital and 2,500 ml. of slightly blood-stained fluid was removed from the right chest. A thoracoscopic examination was carried out on July 27, when a small biopsy was taken but this consisted of fibrous tissue. Bronchoscopy was normal and no neoplastic cells were observed in the bronchial washings. *M. tuberculosis* was not cultured from numerous specimens of sputa, pleural fluid nor from the bronchial washings. She was admitted to a Johannesburg nursing home on October 16, 1958.

Radiographs then showed massive thickening of the right pleura with fluid in the right chest. At thoracotomy (Mr. Dennis Fuller) the parietal pleura was 2 cm. thick, "hard as rock" and stripped with great difficulty from the chest wall. The visceral peel stripped fairly easily from the upper lobe but separation became more difficult over the lower lobe where the peel was thicker. During the decortication a necrotic mass was found in the parenchyma of the left lower lobe. At the base, confluent with the diaphragm and perhaps the mediastinum, was a hard craggy mass which could not be removed. Histological sections of the specimen revealed an adenoid form of tubular mesothelioma. Subsequently three specimens of sputum were examined for asbestos bodies but none were found.

The patient is still alive (April, 1960), but her condition is deteriorating.

Case 22.—D.A.B., a white male, 68 years of age, and a farmer, was the father of the previous patient. Although a diagnosis of pleural mesothelioma was made in January, 1957 it was not until July, 1959 that details of his exposure to asbestos was obtained.

He was born in Griquatown and went to school there. He worked in Kuruman, Postmasburg and Griquatown until the age of 62. Between 1918 and 1932 he worked as an asbestos miner underground and was mostly in charge of blasting. Between 1932 and 1944 he farmed in the district but returned to asbestos mining from 1945 to 1952.

In January, 1957 the patient consulted his doctor because of left-sided chest pain with cough and slight haemoptysis. He was referred to the Johannesburg General Hospital for investigation. The chest radiograph showed gross pleural thickening with a basal pleural effusion on the left side. He was admitted to hospital and on June 10, 1957 a thoracoscopic pleural biopsy was taken. This showed the features of a mesothelioma. On June 24, 1957 an attempt at decortication was made. The left upper lobe was stripped easily but the grossly thickened pleura was so adherent to the lower lobe that the attempt was abandoned. Sections of the pleura confirmed the diagnosis of mesothelioma. He died on December 13, 1957.

Case 16.—A.N.V., a white male, 50 years of age (born 1906), was a farmer, who was born at Griquatown and went to a village school near an asbestos mine. From 1914-16 he transported asbestos in donkey waggons from Hay to Prieska. During these journeys he often slept on asbestos bags. In 1914 he worked in an asbestos mine for a month.

The patient became ill in December, 1955 with vague substernal pain and dyspnoea. A left-sided pleural effusion was diagnosed and he was referred to Mr. J. K. Bremmer in Pretoria. There was no evidence of malignancy in bronchial and scalene biopsies. Some apical pleural thickening and a dense homogeneous opacity at the base of the left lung was seen in the radiograph on August 3, 1956. Thoracotomy (Mr. Bremmer) in February, 1957 revealed a thickened nodular pleura with a large mass on the left diaphragm. A mesothelioma was seen on histological section.

In April, 1959 he was examined by Mr. J. D. Visser in Kimberley who found small nodules in the subcutaneous tissue over the neck and chest. A large firm mass was found in the thoracotomy wound and a mass was present in the left hypochondrium. There was generalized lymphadenopathy and numerous nodules were present on the tongue. Chest radiographs showed the left pleural cavity to be obliterated. He was one of the few cases to develop widespread metastases.

A biopsy of one of the subcutaneous chest nodules showed a similar appearance to those seen in the original specimen from the pleura. The patient died on May 22, 1959. No necropsy was performed.

Case 24.—D.G., a white male, 32 years of age (born 1922), by profession an accountant, was born in England but came to South Africa as an infant. He spent his early childhood in Kuruman and left at the age of 7. He later qualified as a chartered accountant in Kimberley. In 1944, at the age of 22, he had been discharged medically unfit from the army because of a left pleural effusion. Neither then nor on many subsequent occasions were acid-fast bacilli found, either in sputum or pleural fluid. His only subsequent contact with asbestos was the auditing of the books of an amosite mine in the Transvaal.

In September, 1953 he complained of left-sided chest pains and shortness of breath. A radiograph of the chest showed flattening of the diaphragm on the left side with obliteration of the costophrenic angle and thickening of the oblique fissure. He was seen on numerous occasions

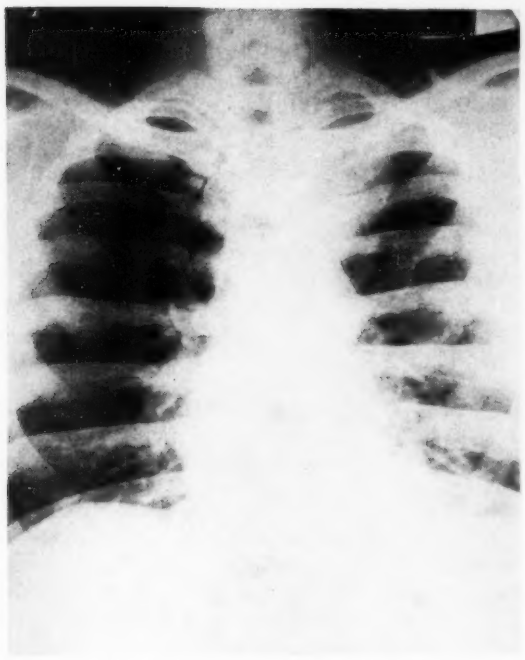

FIG. 11.—On September 11, 1956.

FIG. 12.—On August 23, 1957.

FIGS. 11 and 12.—Radiographs showing development of tumour in Case 24.

from 1953 to 1957. A radiograph taken early in 1956 showed the development of a left superior mediastinal shadow which enlarged progressively (Fig. 11) and later the development of diffuse nodular pleural thickening on the left. During 1957 similar but less marked changes developed on the right side (Fig. 12). He consented to biopsy in June, 1957, and, at operation, a diffuse pleural malignancy was present.

Sections of the parietal pleura only were removed and the histological appearances were those of a mesothelioma. He died on October 6, 1957. A necropsy was not performed.

Case 30.—G.F., a white male, 50 years of age (born 1909), is a storekeeper, with a history of industrial exposure. He has never been near the Cape Asbestos Fields.

He was born in South West Africa and lived there until the age of 21. From the age of 21 to 26 he worked in a factory in the Cape as a boiler-maker and fitter. He volunteered the information that he had worked continuously with asbestos, lagging pipes and boilers. He remarked that the removal of asbestos lagging from old pipes created a very dusty atmosphere and that he would cough a lot at such work. Between 26 and 32 years of age he worked in a factory in Johannesburg in a similar capacity but was not exposed to such heavy dust concentrations. For the past 20 years he had not been in contact with asbestos. Enquiries were made from the factory in the Cape as to the nature of the asbestos used and these have revealed that during the relevant periods Cape crocidolite was exclusively in use.

He was first seen on March 14, 1959 complaining of cough, pain in the right chest and recent onset of breathlessness. Three pints of fluid had been aspirated from the pleura and cytological examination showed the presence of malignant cells. The radiograph showed marked pleural thickening and hydro-pneumothorax. On March 17, 1959, a thoracoscopy was done. The pleura felt thickened and the lung was collapsed and immobile. Several biopsies were taken. These showed the presence of a mesothelioma. The underlying lung showed the presence of asbestosis. He was treated with nitrogen mustard intra-pleurally and his condition temporarily improved. When last examined he complained of increased breathlessness.

Discussion

In 1924 Robertson denied the existence of primary malignant tumours of the pleura and considered them to be secondary in origin. Since then, on the one hand, Willis (1948, 1953) and Smart and Hinson (1957) have supported Robertson's views, while on the other hand, primary neoplasms of this nature have been described by many authors in recent years. These include Tobiassen (1955) in Sweden, Belloni and Bovo (1957) in Italy, Godwin (1957) in the United States, and McCaughey (1958)

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Case 22.—D.A.B., a white male, 68 years of age, and a farmer, was the father of the previous patient. Although a diagnosis of pleural mesothelioma was made in January, 1957 it was not until July, 1959 that details of his exposure to asbestos was obtained.

He was born in Griquatown and went to school there. He worked in Kuruman, Postmasburg and Griquatown until the age of 62. Between 1918 and 1932 he worked as an asbestos miner underground and was mostly in charge of blasting. Between 1932 and 1944 he farmed in the district but returned to asbestos mining from 1945 to 1952.

In January, 1957 the patient consulted his doctor because of left-sided chest pain with cough and slight haemoptysis. He was referred to the Johannesburg General Hospital for investigation. The chest radiograph showed gross pleural thickening with a basal pleural effusion on the left side. He was admitted to hospital and on June 10, 1957 a thoracoscopic pleural biopsy was taken. This showed the features of a mesothelioma. On June 24, 1957 an attempt at decortication was made. The left upper lobe was stripped easily but the grossly thickened pleura was so adherent to the lower lobe that the attempt was abandoned. Sections of the pleura confirmed the diagnosis of mesothelioma. He died on December 13, 1957.

Case 16.—A.N.V., a white male, 50 years of age (born 1906), was a farmer, who was born at Griquatown and went to a village school near an asbestos mine. From 1914-16 he transported asbestos in donkey waggons from Hay to Prieska. During these journeys he often slept on asbestos bags. In 1914 he worked in an asbestos mine for a month.

The patient became ill in December, 1955 with vague substernal pain and dyspnoea. A left-sided pleural effusion was diagnosed and he was referred to Mr. J. K. Bremmer in Pretoria. There was no evidence of malignancy in bronchial and scalene biopsies. Some apical pleural thickening and a dense homogeneous opacity at the base of the left lung was seen in the radiograph on August 3, 1956. Thoracotomy (Mr. Bremmer) in February, 1957 revealed a thickened nodular pleura with a large mass on the left diaphragm. A mesothelioma was seen on histological section.

In April, 1959 he was examined by Mr. J. D. Visser in Kimberley who found small nodules in the subcutaneous tissue over the neck and chest. A large firm mass was found in the thoracotomy wound and a mass was present in the left hypochondrium. There was generalized lymphadenopathy and numerous nodules were present on the tongue. Chest radiographs showed the left pleural cavity to be obliterated. He was one of the few cases to develop widespread metastases.

A biopsy of one of the subcutaneous chest nodules showed a similar appearance to those seen in the original specimen from the pleura. The patient died on May 22, 1959. No necropsy was performed.

Case 24.—D.G., a white male, 32 years of age (born 1922), by profession an accountant, was born in England but came to South Africa as an infant. He spent his early childhood in Kuruman and left at the age of 7. He later qualified as a chartered accountant in Kimberley. In 1944, at the age of 22, he had been discharged medically unfit from the army because of a left pleural effusion. Neither then nor on many subsequent occasions were acid-fast bacilli found, either in sputum or pleural fluid. His only subsequent contact with asbestos was the auditing of the books of an amosite mine in the Transvaal.

In September, 1953 he complained of left-sided chest pains and shortness of breath. A radiograph of the chest showed flattening of the diaphragm on the left side with obliteration of the costophrenic angle and thickening of the oblique fissure. He was seen on numerous occasions

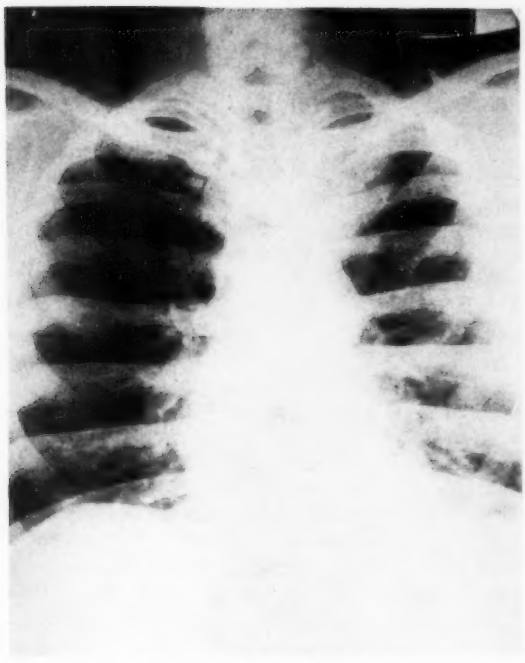

FIG. 11.—On September 11, 1956.

FIG. 12.—On August 23, 1957.

FIGS. 11 and 12.—Radiographs showing development of tumour in Case 24.

from 1953 to 1957. A radiograph taken early in 1956 showed the development of a left superior mediastinal shadow which enlarged progressively (Fig. 11) and later the development of diffuse nodular pleural thickening on the left. During 1957 similar but less marked changes developed on the right side (Fig. 12). He consented to biopsy in June, 1957, and, at operation, a diffuse pleural malignancy was present.

Sections of the parietal pleura only were removed and the histological appearances were those of a mesothelioma. He died on October 6, 1957. A necropsy was not performed.

Case 30.—G.F., a white male, 50 years of age (born 1909), is a storekeeper, with a history of industrial exposure. He has never been near the Cape Asbestos Fields.

He was born in South West Africa and lived there until the age of 21. From the age of 21 to 26 he worked in a factory in the Cape as a boiler-maker and fitter. He volunteered the information that he had worked continuously with asbestos, lagging pipes and boilers. He remarked that the removal of asbestos lagging from old pipes created a very dusty atmosphere and that he would cough a lot at such work. Between 26 and 32 years of age he worked in a factory in Johannesburg in a similar capacity but was not exposed to such heavy dust concentrations. For the past 20 years he had not been in contact with asbestos. Enquiries were made from the factory in the Cape as to the nature of the asbestos used and these have revealed that during the relevant periods Cape crocidolite was exclusively in use.

He was first seen on March 14, 1959 complaining of cough, pain in the right chest and recent onset of breathlessness. Three pints of fluid had been aspirated from the pleura and cytological examination showed the presence of malignant cells. The radiograph showed marked pleural thickening and hydro-pneumothorax. On March 17, 1959, a thoracoscopy was done. The pleura felt thickened and the lung was collapsed and immobile. Several biopsies were taken. These showed the presence of a mesothelioma. The underlying lung showed the presence of asbestosis. He was treated with nitrogen mustard intra-pleurally and his condition temporarily improved. When last examined he complained of increased breathlessness.

Discussion

In 1924 Robertson denied the existence of primary malignant tumours of the pleura and considered them to be secondary in origin. Since then, on the one hand, Willis (1948, 1953) and Smart and Hinson (1957) have supported Robertson's views, while on the other hand, primary neoplasms of this nature have been described by many authors in recent years. These include Tobiassen (1955) in Sweden, Belloni and Bovo (1957) in Italy, Godwin (1957) in the United States, and McCaughey (1958)

in Britain. Evidence in support of the mesothelial origin of these tumours can be found in the tissue culture experiments of Stout and Murray (1942) and Sano, Weiss, and Gault (1950).

The variegated histological pattern of tumours arising from the mesothelium of the pleura was remarked on by Klemperer and Rabin (1931). Such a variation is appreciated when the multipotentiality of the cells lining coelomic cavities are considered. Maximow first demonstrated this feature in 1927. Novak (1931) stated that the mucosa of all parts of the Müllerian canal and the germinal epithelium were derived from these cells. Keasbey (1947) showed that in the embryo, the mesonephros, metanephros, Wolffian body, genital ridge, and all dependent urogenital structures are derived from the mesothelium.

Campbell (1950) considered the presence of both epithelial and mesenchymal elements a major diagnostic feature. In describing the histology of 11 of these tumours McCaughey (1958) demonstrated that either the epithelial or the mesenchymal element might predominate. He classified his cases into the following four groups: Tumours of epithelial character; tumours of mesenchymal type; tumours of mixed type; and tumours of anaplastic type.

Using McCaughey's classification on our series of tumours, the majority are, as in Campbell's series, of the mixed type. Of the remainder, a few showed the papillary tubular structure of the "tumours of epithelial character", and there were several of the anaplastic type. One case had the appearances of a "tumour of mesenchymal type" but even in this case primitive tubular structures were seen.

Apart from the original case all the histological diagnoses were made on biopsy material. Three of these biopsy findings were confirmed at necropsy. In the remainder, we have had to rely on clinical and radiological examination to exclude other primary sites of malignancy.

Following the work of Meyer and Chaffee (1939, 1940), the possibility of demonstrating hyaluronic acid in these tumours both chemically and histochemically has been considered as a diagnostic aid. Both these investigations are still in an early stage (Harington, 1959).

Preliminary results of the histochemical experiments show that there is metachromatic substance in both the stroma and glandular structures of the tumours. This metachromasia can be reversed by incubation with testicular hyaluronidase. This material stains strongly with Hale's (1946) colloidal iron method. The periodic acid Schiff technique has given variable reactions. These results are not specific for hyaluronic acid but are strongly suggestive of its presence.

The amount of metachromatic substance in these tumours has varied considerably. This we think is partly due to the fact that until recently we had not appreciated the solubility of hyaluronic acid in aqueous media and the majority of these tumours were fixed in 10% formol-saline. Further, Lison (1953) states that the metachromasia of hyaluronic acid is optimal at a concentration of 1/10,000 and gradually decreases at higher levels. When the high concentrations that Meyer and Chaffee (1939, 1940) found in their tumours are considered, this variation in metachromatic properties seems to have been partially explained. In addition, with the great differences in the histology of the various lesions, it would be logical to expect certain tumours with a marked adenoid appearance to secrete more than those with an essentially non-glandular structure.

Three of the five autopsies performed showed evidence of peritoneal metastases. In the other two, intra-thoracic spread was observed, in one case to the other lung and chest wall, and in the second to the mediastinal lymph glands and pericardium. Biopsy evidence of metastases has been obtained in two cases, one from the omentum and the other from the subcutaneous tissue of the chest wall; while a third patient developed an implantation nodule in the thoracotomy scar which showed a similar appearance to that of the previous biopsy specimen.

The first recorded case of carcinoma of the lung associated with asbestos was described by Lynch and Smith (1935). By 1955, according to Doll, a total of 61 cases had been reported. Included in these cases was one mesothelioma. Cartier (1952) mentioned two cases of diffuse mesothelioma from a Canadian chrysotile mine. A further three cases were described by van der Schoot (1958). Unfortunately no indication is given in the literature regarding the type of asbestos to which the majority of recorded cases of carcinoma were exposed. However, discussion with management and medical officers of two of the factories, in which the majority of the cases reported in Britain were employed, suggests that most of these workers were handling chrysotile asbestos (Wagner, 1958). The possibility that some of these people may also have been exposed to crocidolite dust cannot be excluded.

Attempts to produce tumours in experimental animals by exposing them to asbestos dust have been made. Vorwald and Karr (1938) were unsuccessful. Lynch, McIver, and Cain (1957) succeeded in producing tumours in mice, but lung neoplasms in his control animals were far too numerous for the results to be considered significant. On the other hand Schmähl (1958) working in Druckrey's laboratory has been able to produce sarcomas in rats. This has occurred after subcutaneous and

intraperitoneal inoculation of both asbestos fibres and dust. He states that "mineral asbestos" was used but does not name the variety.

In our series of mesotheliomata, histological evidence of asbestosis has been observed in eight of the 10 cases in which lung parenchyma was included in the specimen examined. No lung tissue was present in the biopsies from the remaining 23 cases. It was only in the four cases that came to necropsy that large sections of the lung tissue were available for examination. In all of these specimens evidence of asbestosis was found.

At first it was thought that the presence of numerous asbestos bodies, fragments of fibre, and dust immediately below the pleural elastic laminae in these specimens, might have been significant in the pathogenesis of the tumours. However, it is more probable that this distribution is a result of the marked atelectasis. Similar features have been observed in atelectatic lungs of asbestos miners in which no mesotheliomas have been observed.

Pleural fibrosis has been a common finding in cases of asbestosis and in some cases large pleural plaques measuring up to 1·0 cm. in thickness have been seen. These plaques, which were first described by Gloyne (1933), have been observed following exposure to both amosite and crocidolite asbestos dusts. In these cases of benign pleural thickening no evidence of stromal metachromasia has been observed.

In all the histological sections of pleura examined in the cases of these mesotheliomas and in more than 100 cases of asbestosis, no asbestos bodies, fragments of fibres, or dust have been observed beyond the pleural elastic laminae.

Three patients from the Kuruman district, with clinical and radiological features consistent with those of diffuse pleural mesothelioma had markedly abnormal cells in the pleural fluid. These cells showed no specific features to distinguish them from cells originating in secondary malignant pleural deposits nor from the grossly atypical cells sometimes seen in non-malignant pleural effusions. As no biopsy or autopsy examinations were obtained in these cases they have been excluded from the series.

The pathological evidence for associating these tumours with asbestos exposure is not conclusive. As previously stated, only in eight of the 33 cases has evidence of asbestos been demonstrated. Of these, six had a definite mining history and one had been exposed to asbestos while lagging steam pipes. The other case was born in the Kuruman district and nothing else is known of him, until his arrival at a Witwatersrand gold-mine at the age of 23. In the remaining 25 cases we can only present circumstantial evidence of exposure to asbestos dust (Table 3). Eighteen of these 25 cases were born in the vicinity of the mines and two arrived in the district as infants. Of these 18 people 11 admit definite childhood exposure to the dust and two others were exposed industrially in later life. In addition two patients with childhood exposure later worked in the asbestos mines. Three cases arrived in the region at an older age but were employed either on the mines or in transporting asbestos. A further three of these 25 cases have had industrial exposure, and in only one case do the relatives deny any exposure to asbestos dust.

The four industrial cases are significant. Two of the patients were lagging locomotive boilers and one was lagging steam pipes. A man, who was an upholsterer by trade, was employed in making fire-proof clothing from 1939-1945. As far as can be ascertained these people were never in the Griqualand district. These findings tend to add support to asbestos being the common factor in the development of these tumours, and to counter the suggestion that there may be some other environmental cause in the region of Griqualand West.

If asbestos dust is a factor in the occurrence of these tumours, similar cases might have been expected from the neighbourhood of the Transvaal asbestos mines in the Pietersburg and Lydenburg districts, where crocidolite and amosite asbestos is mined. According to Vermaas (1952), crocidolite and amosite occur in the same seams in the Pietersburg district. As can be seen from Table 1, amosite is similar in composition to crocidolite. In the past four years the lungs of 24 cases of asbestosis from the Lydenburg district have been examined. In this material two cases of adeno-carcinoma have been observed. The one was in a white miner with 19 years' service, who had an adeno-carcinoma arising from a bronchus. The other case was a Bantu miner who had a peripheral tumour. No service record was obtainable in this case. Only one case of asbestosis has been received from the Pietersburg area. All of these men were actually employed on the mines at the time of death, the majority having had a relatively short service. Our findings suggest that mesothelioma occurs 20 to 40 years or more after exposure to dust. Until comparatively recently the mining in the Transvaal has been on a small scale, and there were no settlements in the vicinity of the mines.

The lungs of 20 asbestos miners from the Cape Asbestos Field have been examined, in whom no mesothelioma was observed. One autopsy specimen consisting of three fragments of lung showed asbestosis and an adeno-carcinoma. Radiological features of asbestosis have been observed in many miners from this region, without any suggestion of

TABLE 3

DIFFUSE PLEURAL MESOTHELIOMA: ASSOCIATION WITH ASBESTOS

(1) Case No.	(2) Year of Birth	(3) Age at Diagnosis	(4) Race	(5) Sex	(6) Born on Asbestos Fields	(7) Asbestos Exposure	(8) Diagnosed on Biopsy	(9) Necropsy	(10) Histological Evidence of Asbestosis	(11) Survival from Initial Symptoms (in months)
1	1920	36	B	M	+	Other history unknown until came to the Witwatersrand at the age of 23	−	+	+	8
2	±1913	±42	MXD	M	+	Mined asbestos from 1930-33; left area at the age of 27	−	+*	−	29
3	1902	53	B	F	+	Lived whole life in a location near an asbestos mill	+	−	−	11
4	1896	58	W	F	+	Lived on asbestos fields until the age of 5; worked in asbestos warehouse 1916-20	+	−	−	30
5	1925	31	B	M	+	Spent all his working life in the vicinity of mines	−	+*	−	11
6	1903	53	W	F	+	Lived all her life in the vicinity of mines	+	−	−	15
7	1920	36	W	M	+	Lived all his life in the vicinity of mines; worked as a miner	+	−	+	24
8	1894	63	MXD	F	+	From the age of 24 lived in a village serving local mines; often visited mines; watched cobbing outside houses	+	−	−	5
9	1905	52	MXD	M	+	Whole life spent near mines, digging wells	+	−	−	5
10	1909	49	W	M	+	Lived at the mine from age 7-17 years; played on dumps and in mine as a boy; returned to assist from age 21-25	+	−	−	13
11	1898	60	MXD	M	+	Whole life spent near mines; miner 1931-33	+	+	+	12
12	1910	48	B	M	+	Lived near mines until the age of 17; miner 1927	+	−	+	Still alive
13	1909	50	W	F	+	Lived near mine until the age of 21; played with fibre as a child	+	−	−	7
14	1918	40	B	M	+	Whole life spent near mines; miner 1938-41; played on dumps as a child	+	+	+	9
15	1916	42	W	F	+	Daughter of Case 22; lived at mine until age of 20; went to school near cobbing sheds	+	−	−	Still alive
16	1896	60	W	M	+	Went to school near mines; transported asbestos 1914-16	+	−	0	42
17	1911	48	MXD	F	+	Lived on major wagon route till age of 15; several subsequent visits	+	−	−	3
18	1920	38	B	M	+	Whole life in the vicinity of the mines; miner 1945-58	+	+	+	22
19	1922	37	MXD	M	+	Family lived at mine; miner 1938-1959	+	−	+	Still alive
20	1906	53	W	F	+	Spent whole life in village on wagon route to Kimberley	+	−	−	8
21	1912	44	W	M	+	Lived in the vicinity of mines until the age of 16; often on dumps as a child	+	−	−	16
22	1889	68	W	M	+	Whole life in the vicinity of the mines; miner 1913-32, and 1945-52	+	−	−	12
23	1895	63	W	F	+	Lived in the vicinity of the mines until the age of 30	+	−	−	8
24	1922	35	W	M	−	Lived in the vicinity of a mill from the age of 1-7; played on the dumps as a child	−	−	−	48
25	1899	50	W	F	−	Lived in a mining area from the age of 10 to 18 years; after 1918 spent whole life in same town as Case 24	+	−	−	Still alive
26	1895	49	W	M	−	Mined and transported asbestos from 1929-33 as overseer	+	−	−	13
27	1904	52	W	M	−	Born in North West Cape; transported asbestos from 1920-24	+	−	0	15
28	1899	60	W	M	−	Lived whole life on farm in mining area from the age of 12; transported asbestos 1916-21	+	−	−	Still alive
29	1913	44	W	M	−	Maintaining locomotive boilers 1931-45	+	−	−	7
30	1909	50	W	M	−	Maintaining steam pipes in explosive factories 1930-40	+	−	+	Still alive
31	1913	44	W	M	0	Worked as fitter on railways, maintaining locomotive boilers, dates unknown	+	−	−	6
32	1908	49	W	M	−	Making asbestos blankets for the Air Force 1939-45	+	−	−	7
33	1890	59	W	F	−	No history of exposure to asbestos	+	−	−	8

KEYS: Column 4—
Race: W = White
MXD = Mixed (Coloured)
B = Bantu

Column 6
+ = Born on asbestos fields
− = Not born on asbestos fields
0 = Unknown

Column 9—
+ = Necropsy done
− = Necropsy not done
* = Only small fragments of parietal pleura submitted at autopsy for histological examination

Column 10
+ = Positive histological evidence of asbestosis
− = No lung tissue submitted
0 = Small fragments of lung tissue, but no evidence of asbestosis

tumour formation. However, pleural involvement has been a common finding in these cases (Hurwitz, 1959). It is possible that there has not been a sufficient lapse of time after exposure for tumour development in these cases. Further, the factor of individual susceptibility must also be considered.

We wish to record the great assistance that we have received in this investigation from the medical practitioners of the Griqualand West District and the

thoracic surgeons and pathologists in Johannesburg, Pretoria, and Durban.

We thank the Secretary of Health for permission to publish this paper.

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Addendum

By the end of June 1960, a total of 47 cases of mesothelioma had been identified. In 45 of these a possible association with exposure to crocidolite has been established. In one case a mesothelioma of the peritoneum was present.

THE JULY (1960) ISSUE

The July (1960) issue contains the following papers:—

Decompression Sickness during Construction of the Dartford Tunnel. By F. Campbell Golding, P. Griffiths, H. V. Hempleman, W. D. M. Paton, and D. N. Walder.

A Comparison of the " High-altitude " and " High-pressure " Syndromes of Decompression Sickness. By M. de G. Gribble.

Phosgene Poisoning Caused by the Use of Chemical Paint Removers Containing Methylene Chloride in Ill-ventilated Rooms Heated by Kerosene Stoves. By W. B. Gerritsen and C. H. Buschmann.

A Study on the Acute Toxicity of the Tri-aryl Phosphates Used as Plasticizers. By H. F. Bondy, E. J. Field, A. N. Worden, and J. P. W. Hughes.

Aerosol Inhalation of $CaNa_2$E.D.T.A. (Mosatil) by Workers Constantly Exposed to Lead Poisoning. By Lj. Petrović, M. Stanković, M. Savićević, and D. Poleti.

A Biochemical Study of the Urinary Protein of Men Exposed to Metallic Mercury. By J. C. Smith and Agnes R. Wells.

A Simplified Method for the Estimation of Nickel in Urine. By J. Gwynne Morgan.

Clinical, Bronchographic, Radiological, and Physiological Observations in Ten Cases of Asbestosis. By G. L. Leathart.

The Measurement of Occupational Mortality. F. D. K. Liddell.

Observations on the Occupational Life History of the Coal Face Worker at Two Collieries. By O. P. Edmonds and D. S. Kerr.

The Assessment of Electroencephalographic Changes and Memory Disturbances in Acute Intoxications with Industrial Poisons. By B. Chalupa, J. Synková, and M. Ševčík.

Book Reviews.

A number of copies are still available and may be obtained from the Publishing Manager, British Medical Association, Tavistock Square, W.C.1, price 17*s.* 6*d.*

Brit. J. industr. Med., 1960, **17**, 272.

DUST DISEASES IN DUNDEE TEXTILE WORKERS

AN INVESTIGATION INTO CHRONIC RESPIRATORY DISEASE IN JUTE AND FLAX INDUSTRIES

BY

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A survey of respiratory symptoms and function was carried out in Dundee among 123 men and women in the jute industry and 242 in the flax industry. The selection of workers was biassed in favour of those working in the dustier departments as judged by eye and those in the older age groups. A group of 72 men in a heavy engineering firm were also selected as controls for comparison.

Chronic bronchitis, as defined by Ogilvie and Newell (1957) was recorded in 27% of those interviewed, whose average age was 49. Byssinosis of various grades was recorded in 30% of all working in flax; of these 35 had cough alone worse on Monday, 34 had other respiratory symptoms worse on Monday and in only four persons did the exacerbation persist longer in the week.

In spite of the occurrence of byssinosis, chronic bronchitis was no more prevalent among flax workers than among the others, the average ventilatory function was no worse, and radiographs of the chest revealed no differences. The characteristic fall in expiratory flow rate during the course of exposure to flax dust on Mondays is similar to that found in cotton workers, and is absent in jute workers and in flax workers not admitting to symptoms of byssinosis.

During the 18th and 19th centuries attention was drawn to the prevalence of cough and asthma in hemp, flax, and cotton industries (Ramazzini, 1700; Patissier, 1822; Thackrah, 1832). Reference to exacerbations of respiratory symptoms in employees in such trades on Mondays (now referred to as Monday fever) was made by Greenhow (1862). Confirmation of these findings is found in recent publications (Werner, 1955; Doig, 1956), while Schilling (1956) in his Milroy Lectures has reviewed the literature of byssinosis in cotton workers in the Lancashire mills.

Another textile industry producing dust is the manufacture of jute, of which little or nothing is yet known about the respiratory effects, although brief reference has been made to it by Arlidge (1892) and Schilling (1956). While this study was designed to prove the presence or absence of dust disease in jute workers, it was found useful in the course of the investigation to make comparisons with workers in flax.

Historical

Jute is a vegetable fibre which has been cultivated in India for 2,000 years, in areas now known as East Pakistan and Indian Bengal. There are two types of jute fibre, *Corchorus capsularis* and *C. olitorius*, which are annual plants with long, erect, thin stems growing to a height of 10-12 ft. or more (Macmillan, 1935). Harvested after four to six months, usually in the period July-October, jute is then subjected to the process of "retting" which involves steeping the plants in stagnant streams or ponds for periods up to a few weeks. Retting separates out the fibres which lie between the central wooden core and outside bark. Jute fibres are then dried in the sun and classified according to colour, strength, and fineness. Since it was first imported from India some 140 years ago, the manufacture of jute in Great Britain has been largely concentrated in Dundee and district. Before this, the chief textile was flax, which was both grown and manufactured in this area. Gradually, however, jute has

replaced flax in importance, until only two flax firms now remain, compared with approximately 50 jute firms operating within the city alone.

The processes in the manufacture of jute are largely those of any other textile industry although terminology may differ; the initial processes of batching, preparing, carding, and roving are carried out in the "mill", while spinning, cop and spool winding, weaving, and finishing are done in the "factory". In general terms, and within each firm, the "mill" is considered to be dustier than the "factory".

The Investigation

In all, 437 employees were included in the study. While our concern was primarily the existence or otherwise of dust disease in jute workers, employees from a flax and an engineering firm were included to provide comparative data from dusty and non-dusty conditions respectively. In order to find workers who had been exposed for lengthy periods in dusty occupations, the initial selection was of all males aged 40 years and over working in the mill sections of jute and flax works, where the dustiest processes of "preparing" take place.

In addition, systematic sampling from lists of names, provided by the management, was carried out among workers aged 40 and over, including women, working in other departments of flax and jute factories, and the same method of selection was used for men in the engineering works. The proportion chosen varied inversely with the size of the department, being as low as 1 : 8 for some large weaving flats. A small group of younger workers was also included at a later visit to the flax mill.

TABLE 1

	Number Interviewed			Average Age in Years	
	Male	Female		Male	Female
Jute	87	36	123	51	49
Flax					
Mill (1st visit)	62	20		52	49
(2nd visit)	35	31		32	36
Factory	60	34	242	54	51
Engineering	72	—	72	52	—
Totals	316	121	437	50	48

All 437 subjects (316 men and 121 women) were interviewed using a standard questionnaire,* when both an occupational and symptomatic history were taken, the latter by the same doctor (D.H.S.) throughout the survey.

* The standard questionnaire used was similar in all main essentials to that which was being prepared by the M.R.C. Committee on the Aetiology of Chronic Bronchitis.

Male subjects who admitted to certain symptoms suggestive of respiratory disease, and about a third of males who did not, 153 in all, were subjected to a physical examination (W.L.) limited to the respiratory and cardiovascular systems (see Table 2). No physical examination was carried out in women.

TABLE 2

PROCEDURE

		No. of Subjects
(1) Interview with occupational and symptomatic history		437
(2) Clinical examination (for males only)		153
(a) selected on account of history	115	
(b) random selection	38	
(3) Ventilatory function tests (both sexes)		202
(a) selected on account of history	150	
(b) random selection	52	
(4) Comparative tests on Mondays and Thursdays		22
(a) in flax workers	14	
(b) in jute workers	8	
(5) Radiological examination of matched groups		78
(a) jute workers	24	
(b) flax workers	30	
(c) engineering workers	24	

In addition, all those employees both male and female with a similar history of respiratory symptoms, and a sample of those who had none (202) performed certain ventilatory function tests.

Final steps in the investigation concerned the study of ventilatory function in eight jute and 14 flax workers and the comparative radiological study of 78 employees in the three industries.

Results of the Investigation

Uncertain of what clinical or radiological findings might emerge, we proceeded on the basis of symptoms to make a final assessment and diagnosis of any one or more of several respiratory diseases. Of these, four groups or categories were considered relevant, and among the 437 employees the following were diagnosed (see Table 3).

Chronic Upper Respiratory Catarrh.—This condition, characterized by persistent stuffiness of the nose and constant hawking, was diagnosed in 161 individuals.

Chronic Bronchitis.—The definition of Ogilvie and Newell (1957)* was adopted. Chronic bronchitis of the "simple" variety was considered to be present in 88 subjects, while "complicated" bronchitis was found in 31.

* Definition: Chronic bronchitis is a long standing condition, the essential features of which are cough with sputum persistent through the winter or throughout the year in the absence of other causative respiratory disease. A minimum duration of two years is essential.

TABLE 3

DIAGNOSIS BASED ON SYMPTOMS (Standard questionnaire)

Diagnosis	No.
Chronic upper respiratory catarrh	161
Chronic bronchitis:	
Simple (cough and sputum for at least two years)	88
Complicated (cough and sputum for at least two years with breathing difficulties)	31
Cough worse on Monday only	35
Byssinosis:	
Grade I—Tightness in chest and/or breathiessness on Monday only	34
Grade II—Tightness in chest and/or breathlessness on Monday and other days	4

Byssinosis.—This condition Grade I as defined by Schilling, Hughes, Dingwall-Fordyce, and Gilson (1955) was diagnosed in 34 subjects, while an additional four were found to have the condition described as Grade II. None of these 38 persons was employed in jute; all were flax workers. On the basis, therefore, of these generally accepted definitions and adopting diagnoses based on symptoms and history, there appears to be no byssinosis in jute workers, but symptoms of a mild form of byssinosis among flax workers.

Monday Cough.—In addition to these categories of chronic bronchitis and byssinosis as defined, a different and distinct symptom group became apparent, consisting of 35 individuals who gave a history of "cough alone worse on Monday". No jute employees were in this group; all were employed in flax, although we found two jute workers who did give equivocal histories of "cough worse on Mondays". The clinical histories of these two employees are as follows:

CASE 112.—Jute worker, age 51, with a history of textile dust exposure for eight years (flax four, jute four), had cough, sometimes worse on Monday night (works on night shift). He had been employed in flax as well as jute.

CASE 115.—Jute worker, age 53, with a history of textile dust exposure for seven years (flax four, jute three), had no cough, but admits to slight sputum on Monday. He had worked in flax as well as jute.

Although now employed as jute workers, each had previously worked for four years in flax.

"Chronic bronchitis" may lack precision as a pathological diagnosis, but its value in clinical and epidemiological work is undoubted. Moreover, the chronic effects of vegetable dusts are not easily distinguishable from non-occupational bronchitis (Hunter, 1957). Since grouping as bronchitis might well conceal an undue prevalence of dust disease in jute workers, an attempt was made to unmask any such effect by comparing the prevalence of chronic bronchitis as between one industry and another (see Table 4) in employees 40 years of age and over.

In all three industries, a total of 82 (29%) men were diagnosed as having chronic bronchitis, whereas only 14 (14%) women employees had these symptoms; this difference is highly significant statistically ($p = \cdot001$). Differences between industries, dusty and non-dusty, were not significant. Differences in the three industries again were not significant, the mean percentage prevalence in male jute workers being 36% compared with 22% among males in flax, while engineering employees in non-dusty work held an intermediate position of 34%. The low figure of 22% in flax may be accounted for by the fact that there were fewer smokers in flax than in jute workers.

TABLE 5

ALL WORKERS CLASSIFIED BY YEARS OF EXPOSURE TO DUST

Years of Exposure	Numbers of Workers
Nil	34
< 9	91
9–	80
19–	109
29–	76
39–	47
Total workers in Survey	437

Dust Exposure.—In order to ensure sufficient numbers with lengthy dust exposure, the initial selection of employees was largely limited to those aged 40 years and over. Our objective in so doing (see Table 5) appears to be well nigh achieved. All

TABLE 4

CHRONIC BRONCHITIS IN WORKERS AGED 40 AND OVER

Industry	Males				Females			
	No. in Group	Mean Age (Years)	With Bronchitis		No. in Group	Mean Age (Years)	With Bronchitis	
			No.	%			No.	%
Jute—Firm A	25	51	10	40 } 36	25	49	3	12 } 11
Firm B	58	51	20	34	11	52	1	9
Flax—Mill	67	52	11	16 } 22	30	52	5	17 } 15
Factory	58	55	17	29	34	51	5	15
Engineering	70	53	24	34	—	—	—	—
Total	278	53	82	29	100	51	14	14

TABLE 6
BYSSINOTIC SYMPTOMS AMONG FLAX WORKERS

Symptoms	No. of Years of Exposure to Dust					Total
	0–	10–	20–	30–	40–	
Monday cough	7	9	9	5	5	35
Byssinosis—Grade I	8	8	9	5	4	34
Grade II	0	1	2	1	0	4
Total no. with symptoms	15	18	20	11	9	73
Total no. of workers at risk	59	50	53	45	35	242
Expected no. with symptoms of uniform proportion	17·8	15·1	16·0	13·5	10·6	73

NOTES: Chi-squared 2·7; degrees of freedom 4; probability of arising by chance between 0·7 and 0·5

workers, textile and engineering, are included as 38 out of 72 engineering employees had previously worked in jute for short periods.

There are 232 employees with over 20 years' exposure. The relatively large number, 91, with less than nine years' exposure, contains most of the engineering workers with brief exposure. Those 59 examined at the second visit to the flax firm were 39 years of age or less. Both reasons would account for a considerable proportion of employees with less than 20 years' dust exposure. In Table 6 byssinosis Grades I and II are shown in relation to years of dust exposure.

It is common for workers to move from one firm to another, or from one industry to another. Thus more than half of the workers examined in the engineering firm had worked in jute, and to a much less extent flax, at some time in the past; and many of those now working in flax had also worked in jute in the past.

The development of symptoms of byssinosis or of "cough worse on Monday" appears to be unrelated to length of time of exposure to flax dust, and cases were found among those who had worked only a few months in flax. In Table 6 the distribution of workers with these symptoms among the workers with various lengths of dust exposure is in good agreement with the expected numbers, based on the total number of persons in each group.

Dust Counts in Jute.—Dust counts with a Kotze koniometer were attempted, but the results were not considered sufficiently reliable. We were fortunate in having the advice of an expert with experience in cotton and other industries (Mr. S. A. Roach). He considered, from visual impressions, that even the dustiest departments in jute compared favourably with other textile processes. Using a Hexhlet dust sampler in the batching department of one of the jute firms, he obtained a dust sample with the following composition:

Size of Dust	Jute Firm "A"—Batching Department Concentration (mg./100 cu. m.)			
	Cellulose	Plant Debris	Minerals	Total
Fine	14	4	13	31
Medium	40	11	87	138
Coarse	191	35	152	378
Totals	245	50	252	547

These findings confirm earlier visual impressions and compare favourably with conditions in the carding rooms of cotton mills where the total dust count may reach figures of 900 mg./100 cu. m. total dust (Roach and Schilling, 1960).

Ventilatory Function Tests.—Tests of forced expiratory volume (Table 7) were performed on all workers with histories suggesting respiratory disease together with a sample of those with none, in order to assess their degree of ventilatory disability. The tests were not employed primarily to compare industries but as a means of detecting individuals with respiratory disability in our search for any deleterious effect of dust. The two conditions upon which our interest was mainly focused were byssinosis and chronic bronchitis.

TABLE 7
AVERAGE VENTILATORY FUNCTION OF WORKERS IN DIFFERENT FACTORIES

	Jute		Flax		Engineering	Total
	Firm A	Firm B	Firm C		Firm D	
			Mill	Factory		
No. tested	31	37	43	50	41	202
Average indirect M.B.C./predicted M.B.C.%	83·3	80·3	78·1	84·1	83·7	82·0

A large proportion of the persons tested were selected because of having respiratory symptoms and so were not representative of the industry from which they were chosen. The mean values of ventilatory function given in Table 7 therefore tend to be too low, but it is believed that any difference between the factories would have been accentuated by this method of selection. If any factory did, in fact, have more persons with respiratory disability, a larger proportion of such persons and fewer normal persons would have been selected. As a result, the mean value of ventilatory function tests of employees in each industry is depressed and the difference between results in such industries accentuated. Even with this bias, differences between industries were not significant.

The instrument used was a spirometer of the type described by Bernstein, D'Silva, and Mendel (1952). From the ink tracing the 0·75 second forced expiratory volume F.E.V. $_{0\cdot75}$ was measured and the best of three readings selected. In order to reduce the differences between the sexes and the effect of age and body build, the ratio of the indirect maximum breathing capacity or M.B.C. (Kennedy, 1953) to the predicted value of the maximum breathing capacity (Needham, Rogan, and McDonald, 1954) was used.

The standard deviation for this ratio in the whole series was 22·9% so that the fluctuations from factory to factory are no more than would be expected by chance, and there is no indication that the general level of ventilatory function would be less in one industry compared with the others.

Tests of Ventilatory Function in Jute and Flax Workers.—When it became evident in the course of our survey that there was an appreciable prevalence of byssinosis in flax workers, it was decided to ascertain whether the ventilatory function of these subjects with byssinosis reacted in a similar manner to that of cotton workers with this disease (McKerrow, McDermott, Gilson, and Schilling, 1958). In such event would jute workers behave similarly?

Seven flax workers with byssinosis and seven without byssinosis were compared. Tracings of the forced expiratory volume were made on a "Mendel" type spirometer three times during the day on Monday and on Thursday—7.30 a.m., 11 a.m., and 4.30 p.m. At a later date eight jute workers were investigated in a similar manner, but using a modified Gaensler (1951) spirometer (McKerrow, McDermott, and Gilson, 1960). The results are shown in Fig. 1.

An attempt was made to match the subjects investigated, half being as normal as possible, and half being disabled by respiratory disease.

The fall on Monday in the F.E.V. $_{0\cdot75}$ of byssinotics (0.42 l./min., S.E. = 0·13) is just significant, whereas the fall on Thursday is smaller (0·25 l./min.) and fails to reach the level required for statistical significance at the P.05 level. Among jute workers and non-byssinotic flax workers the changes are far less obvious.

Radiological Examinations.—While it is known that in the absence of fibrosis there are no characteristic radiological findings in byssinosis of cotton workers (Hunter, 1957) we had no knowledge of whether the jute dust did in fact possess any fibrogenic qualities on inhalation. Apart from vegetable dust, a considerable amount of mineral dust is also shaken out in the early processes of batching and preparing. Chest radiographs were therefore taken of 78 men, 40 years of age and over, a third from each industry who were known to have worked only in their respective industries. Half of them in each industry had marked histories of respiratory disease and half had none. One lateral and two postero-anterior films were taken, developed under standard conditions and technique (Fletcher, Mann, Davies, Cochrane, Gilson, and Hugh-Jones, 1949) and were read by seven observers who were unaware of the identity of each film. Particular attention was paid to findings which might suggest the earliest phases of pneumoconiosis, the presence or effect of dust, stages of reticulation, or increase in non-vascular pattern of the lung. This part of the investigation was essentially negative. No radiological changes were found which could be accounted for by differences between industries.

In addition to our main interest in dust disease among jute workers, we also sought any relationships between abnormalities of the nasal sinuses and diseases of the chest, but no such relationship was found.

Discussion

The description of respiratory disease in textile workers a 100 years ago is a striking and arresting one. The workers "are seen at a glance to be short-breathed; their rounded shoulders, emaciated frames, prominent eyes and laborious wheezing respiration, all clearly show that they suffer habitually from dyspnoea" (Greenhow, 1862). Asthma, according to the New Statistical Account of Scotland (1845) was endemic in Dundee. By contrast, in the present survey not a single textile worker among the 314 interviewed complained of asthma. Ventilatory function in textile workers is equal to that of engineers, and symptoms of chronic bronchitis are no more frequent.

Men working in jute attracted attention by their

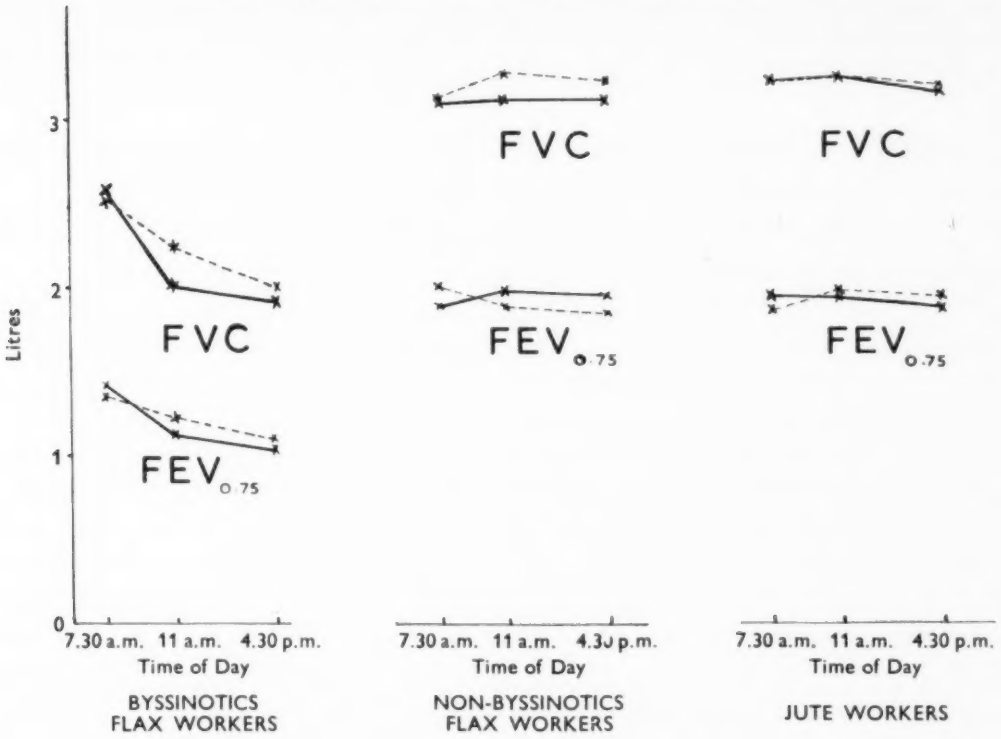

FIG. 1.—Changes in ventilatory function on Mondays and Thursdays. ——— Monday; - - - - - - - - Thursday.

poor physique, and rather more of them were found to have dyspnoea of severer grades. This could be attributed to other conditions (spinal, skeletal, or heart disease) and to the recruitment as unskilled labour of partially incapacitated workers.

The finding of byssinosis among flax workers was the only respiratory condition associated with the textile industries investigated by us in Dundee, and invites comparison with byssinosis among cotton workers as described by Schilling *et al.* (1955). Although the general picture is similar, with tightness of chest, breathlessness, and respiratory disability worse on Monday, and a small proportion of workers continuing to be disabled on Tuesday and other days of the week, yet there are differences which may prove to be important in throwing light on the mechanism of byssinosis in various industries.

(1) Cotton workers are more prone to develop byssinosis if they work in the card-room or blow-room; this applies, in particular, to strippers and grinders (Schilling, 1956); by contrast, byssinosis occurs in all departments of the flax mill and factory studied by us. This finding is in agreement with the opinion of those working in the industry, and our own visual observations, that fine dust floating in the air is found throughout the flax process, right up to the finishing stage.

(2) Byssinosis in flax workers appears to be independent of length of time of exposure to flax dust, and was found in persons with only a few months exposure. Schilling *et al.* (1955) found more byssinosis among cotton workers who had worked 10 years or more in the industry; this was not found by us in flax.

(3) So far no evidence has been found that byssinosis in flax workers produces any serious disability, and it seems to be a milder disease than in cotton workers. Only 10% of flax workers with byssinosis were in Schilling's Grade II, compared with 40% of the cotton workers reported by him (Schilling *et al.*, 1955). No significant reduction in ventilatory function could be demonstrated in flax workers with byssinosis when comparing groups in whom other disease conditions such as chronic upper respiratory catarrh, simple bronchitis, and complicated bronchitis are equal, whereas in cotton workers the ventilatory function is reduced. Dyspnoea of Grade III or worse was found in only

one flax worker with byssinosis (a woman) out of a total of 38 persons affected; in cotton workers the percentage varied from 8 to 25 according to the day on which the workers were interviewed (Schilling *et al.*, 1955).

The relationship of byssinosis to chronic bronchitis is obscure. In cotton workers a clear distinction was postulated between bronchitis, where cough is made worse by exposure to undue concentrations of any dust on any day of the week, and byssinosis, where symptoms are worse following exposure to cotton dust on Monday. In flax the situation is complicated by a group of workers whose cough is the only respiratory symptom worse on Monday, but who do not qualify for diagnosis as byssinosis otherwise.

The possibility of exposure to flax dust giving rise to bronchitis or to symptoms masquerading as bronchitis must be considered. This is unlikely, since the proportion of workers diagnosed as having chronic bronchitis was lower in the flax industry than in the other two industries studied. The comparison is complicated by a higher proportion of non-smokers in the flax industry; possibly the inhalation of flax dust may discourage smoking.

Briefly, therefore, certain flax workers diagnosed as suffering from byssinosis seem to differ both in severity of symptoms and length of dust exposure from cotton workers with byssinosis. This finding and the presence of a group of flax workers whose cough is worse on Monday will require further study and elucidation.

We are particularly indebted to the management of the four firms and to the employees who cooperated so wholeheartedly.

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The services and expert advice of Mr. S. A. Roach in matters appertaining to dust analysis have been of much help.

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THE STUDY OF OBSERVER VARIATION IN THE RADIOLOGICAL CLASSIFICATION OF PNEUMOCONIOSIS

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In a long-term investigation such as the National Coal Board's Pneumoconiosis Field Research (P.F.R.), it is essential to establish satisfactory and stable procedures for making the necessary observations and measurements. It is equally important regularly to apply suitable methods of checking the accuracy and consistency of the various observations and measurements. One aspect of vital importance in the P.F.R. is the classification of the series of chest radiographs taken, at intervals, of all the men under observation. This is inevitably a subjective process, and (as with other similar fields of work) it is desirable to obtain some understanding of the basic process behind the operation. This can usefully be done by the help of "models" designed to describe the process, if necessary in simplified terms. The problem of the radiological classification of pneumoconiosis has been studied hitherto in terms of coefficients of disagreement (inter-observer variation) and inconsistency (intra-observer variation), but for various reasons the method was not considered entirely satisfactory. New methods of approach were therefore developed for studying the performance of the two doctors responsible for the film reading in the Research, and two distinct "models" were derived. The advantages and disadvantages of each are described in the paper, together with the applications of the two models to the study of some of the problems arising in the course of the investigation.

The first model is based on the assumption that if a film is selected at random from a batch representing a whole colliery population, and that if the film is of "true" category i, the chance of its being read as another category (j) is a constant, p_{ij}, which depends upon the observer concerned, the particular batch of films being read, and the values of i and j. This model enables the performance of the readers to be monitored satisfactorily, and it has also been used to investigate different methods for arriving at an agreed, or "definitive", assessment of radiological abnormality. The p_{ij} model suffers from the disadvantage of applying only to "average" films, and the assumptions made are such that it manifestly does not provide an entirely realistic representation of the reading process on any particular film.

The second "improved" model was therefore developed to overcome this criticism. Briefly, it is considered that each film is representative of a unique degree of abnormality, located on a continuum, or abnormality scale, which covers the whole range of simple pneumoconiosis. The scale of abnormality is then chosen in such a way that, whatever the true degree of abnormality of the film, the observer's readings will be normally distributed about the true value with constant bias and variability at all points along the scale. The very large number of readings available has been analysed to determine the optimum positions of the category boundaries on the abnormality scale and in this way the scale has been unambiguously defined. The model enables the routine reading standards to be monitored, and it has also been used to investigate the underlying distribution of abnormality at individual collieries. Its chief disadvantage is the extensive computational work required.

The "fit" of both models to the data collected in the Research is shown to be satisfactory and on balance it appears that both have applications in this field of study. The method chosen in any given circumstance will depend upon the particular requirement and the facilities available for computational work.

Two of the objectives of the National Coal Board's Pneumoconiosis Field Research (Fay, 1957) are (1) to express the present prevalence of pneumoconiosis at about 25 selected collieries in terms of its various stages of severity as measured by radiological examination, and (2) to investigate the progression of pneumoconiosis at these collieries, also in terms of radiological examination. It was therefore essential, at the beginning of the Research, to agree upon uniform procedures to be adopted by the two medical officers responsible for taking and reading the radiographs.

A good deal of experience and advice was available, particularly from members of the Pneumoconiosis Research Unit (P.R.U.) of the Medical Research Council, and after careful consideration it was decided that each film should be read independently at least once by each doctor. When these routine readings agreed the common assessment was taken as the "definitive" classification. In the event of disagreement the film was read by both doctors in consultation and the "definitive" classification was agreed upon by joint discussion. This procedure is such that the "easy" films are disposed of quickly but the more "difficult" ones are classified only after joint discussion by the two readers.

It is generally accepted that the classification of radiographs for pneumoconiosis is subject to variation (Fletcher and Oldham, 1949), and it is therefore necessary to maintain a check upon the performance of the two doctors, as regards both agreement with one another and consistency within their own performances from time to time. The available methods for analysing the data were not considered to be entirely satisfactory and early in the Research a relatively simple mathematical model was developed as an aid to the assessment of the readings (Ashford, 1956). Although useful for many purposes this model applies only to the study of "average" effects, as represented by randomly selected single films or by large numbers of films, and not to particular individual films. To obtain a more exact representation of the reading process a more complicated model, based on the concept of a continuous scale of abnormality, was therefore developed (Ashford, 1959).

This paper describes the application of the two models to a number of problems concerned with the reading of radiographs which have arisen during the course of the Pneumoconiosis Field Research. The methods cover only two out of a number of possible ways of representing the film reading process in quantitative terms and alternative procedures are currently under consideration both by the National Coal Board and by the Pneumoconiosis Research Unit.

Method of Approach

Reading radiographs for pneumoconiosis is a complex procedure, involving the recognition and interpretation of the characteristic opacities on a background of other lung markings, and a precise mathematical description of the process would be impracticable. As in many similar fields of study it is, however, helpful to consider the problem in terms of a simple theoretical model (or models) to represent the process of classification in mathematical terms. On the basis of the theoretical model it is then possible to derive a quantitative measure of the accuracy of the reading process.

Any acceptable model must satisfy three main requirements:—

(a) It must "fit" the observed data. That is to say, the results obtained by assuming that the model is true must agree with the actual observations.

(b) The general assumptions involved in the model must be consistent with the nature of the reading process, *i.e.* the model must be realistic if it is to assist those concerned with making the observations.

(c) It must be relatively simple, both in conception and application, as far as this is possible.

The choice of one particular model rather than another must represent a compromise between these three considerations. Although requirements (b) and (c) are to some extent a matter of opinion, an objective measure may be obtained of requirement (a). Thus, other things being equal, the most acceptable model is the one which provides the best "fit" to the observations.

Classification of Films

The categories of pneumoconiosis used in the radiological surveys are based on the P.R.U. classification, and are those which were currently accepted by international agreement, which recognizes a distinction between "simple" and "complicated" pneumoconiosis (International Labour Office, 1953).*

Simple pneumoconiosis is divided on a quantitative basis into three categories, increasing in degree of abnormality and numbered 1 to 3, category 0 being reserved for films that are within normal limits. The lower limit of the continuum of abnormality is represented by a film of a person who has never been exposed to airborne dust, showing none of the specific changes associated with simple pneumoconiosis, and the upper limit by a film on which no further increase of simple pneumoconiosis can be detected. The location of the various

* The International Labour Office, 1953, classification has since been revised, but the revised criteria were not used for the work described in this paper.

categories on this continuum is subjective. The boundaries between categories 1 and 2 and between categories 2 and 3 are defined by means of standard films which illustrate borderline cases. Category 1 is defined by means of standard films which represent typical examples of the category (Fletcher and Oldham, 1951).

Complicated pneumoconiosis (Progressive Massive Fibrosis or P.M.F.) is divided separately into four categories—A, B, C and D. P.M.F. is commonly believed to occur only on a background of at least category 2 of simple pneumoconiosis and it differs qualitatively from the latter condition. In no sense can any of the categories of P.M.F. be said to lie on the continuum of simple pneumoconiosis, although it might be asserted that a film showing evidence of P.M.F. must have reached at least the lower boundary of category 2.

When the surveys were first started each film was read three times, twice by the doctor responsible for the survey at the particular colliery (each was responsible for the surveys at half the collieries, divided roughly on a regional basis (Fay, 1957)) and once by the other doctor. This procedure was later modified in the light of experience (see below) and the second reading by the doctor responsible for the survey was discontinued.

Previous Method of Analysis

At the beginning of the research use was made of such experience as had been reported in the literature (Fletcher and Oldham, 1949) and the analysis of the film readings was based on two main concepts, those of "agreement" (with the definitive category) and "consistency" (between repeat readings by the same observer), which were expressed in quantitative terms as coefficients of disagreement and inconsistency respectively. The calculation of these coefficients was based on the assumption that the categories of pneumoconiosis may be treated as real numbers, which further implies that the categories are linearly related. That is to say, the difference between one category and the next is the same whatever the categories concerned, and hence the differences are additive. In view of the nature of the process of radiograph classification the validity of this assumption, especially with reference to the relationship between complicated pneumoconiosis and the various categories of simple pneumoconiosis, is subject to doubt. Statistical tests of the significance of the difference between corresponding coefficients were based on the extension of methods of analysis for continuous distributions to the essentially discrete distributions of film readings. The validity of this extension is also subject to some doubt on mathematical grounds. For these reasons the available methods of analysis were considered to be far from satisfactory, and alternative procedures were investigated.

The "p_{ij}" Model

The "p_{ij}" model (Ashford, 1956) is based on the assumption that there exists a unique "true" category associated with any given film, this true category being defined as the opinion which would be obtained most frequently in a long series of joint readings by the two observers in consultation. The model then assumes that, if a film is selected at random from a batch representing a complete colliery population, and if the film belongs to true category i, the chance of reading the film as category j is a constant, p_{ij}, where p_{ij} depends on the observer concerned, the particular batch of films being read, and the values of i and j. For example, if an observer is examining a film which happens to belong to true category 0, it is assumed that the chance of his reading it as category 0 is a constant (p_{oo}), depending on the performance of the observer at the time of reading and on the batch of films concerned. If the observer is reading accurately, p_{oo} will be close to unity, whereas p_{o1} (the chance of the true category 0 film being read as category 1) will be correspondingly small, and p_{o2}, p_{o3}, p_{o4}, and p_{o5} will be negligible.

For the purposes of the model, category A of P.M.F. is considered as a separate category (labelled "4") and categories B, C, and D are taken together as a single category (labelled "5"). Thus the model is applied to both simple and complicated pneumoconiosis. In that no difference is made between two distinct aspects of the reading process it is obvious that some measure of validity has been sacrificed in the interests of simplicity of treatment.

As regards the classification of simple pneumoconiosis, it is evident that the chance of reading any single film as one category rather than another is highest when the film is near a category boundary. In the extreme case of a film which is exactly on the boundary between two categories it seems reasonable to suppose that the observer will be equally likely to assign it to the higher or lower category in the absence of reading bias. Indeed, this model obviously represents a simplification of the actual process of classification and in any particular case it may be expected that the probability of error will vary according to whether or not the film is on the borderline between two categories. Again, the model applies only to studies of the variations associated with the readings on films representing complete colliery populations (with which the

TABLE 1

TEST OF THE "p_{ij}" MODEL WITH THE OBSERVED DATA
NUMBERS OF OCCURRENCES (OBSERVED AND EXPECTED) OF THE VARIOUS SEQUENCES OF ROUTINE READINGS
(All films)

Colliery	C_2		C_4		C_9		C_3		C_{11}	
Prevalence of Category 1 or More Pneumoconiosis	42%		33%		21%		9%		5%	
Sequence	Observed	Expected	Observed	Expected	Observed	Expected	Observed	Expected	Observed	Expected
(0, 0, 0)	361	365	436	426	1,337	1,341	1,336	1,313	1,167	1,165
(0, 0, 1)	21	18	5	1*	46	31*	56	49	24	23
(0, 1, 0)	43	46	37	40	12	13	15	38*	5	7
(1, 0, 0)	18	17	28	34	16	15	13	36	9	12
(0, 1, 1)	19	12*	4	6	13	21*	11	11	3	5
(1, 0, 1)	4	2	2	4	9	16*	6	10	5	6
(1, 1, 0)	36	28	43	31*	32	27	36	13*	5	3
(1, 1, 1)	28	46*	18	19	54	50	27	27	13	9
(1, 1, 2)	16	14	4	2	23	11*	11	7	7	3*
(1, 2, 1)	11	9	12	11	7	8	3	4	0	2
(2, 1, 1)	5	4	3	7	0	5*	1	2	0	2
(1, 2, 2)	11	10	9	12	10	16	2	3	0	3
(2, 1, 2)	8	7	2	4	2	6	2	2	1	3
(2, 2, 1)	13	8*	21	13*	18	10*	4	3	4	1*
(2, 2, 2)	21	25	30	22	33	27	10	8	8	6
(3, 3, 3)	13	13	8	6	11	9	2	2	3	2
(4, 4, 4)	15	16	16	16	18	12	1	1	3	2
(5, 5, 5)	29	29	5	4	14	14	1	1	2	2
All others	87	90	44	69*	70	93*	29	36	10	13

* Value of χ^2 in excess of 3·0.

Pneumoconiosis Field Research is mainly concerned). Readings on specially selected batches of films may well follow a different pattern. This means that the model is intended to refer only to the study of "average" effects based on large numbers of films representing complete colliery populations and should not be extended to cover any particular film.

If the true distribution of abnormality in a batch were known, estimates of the probabilities, p_{ij}, would be given by the proportion of films of true category i which were read as category j. In practice, however, the true category of any particular film cannot be obtained and the estimates of p_{ij} must be calculated in terms of the proportion of films of definitive category i which are read as category j on the particular set of readings. Although it is shown subsequently that the definitive category may be incorrect on an appreciable proportion of films, the overall distribution of abnormality in terms of the definitive readings is reasonably close to the true situation as defined above, and hence the use of the definitive readings to represent the true values is justified in the application of the model.

In the light of these considerations the question arises as to how well the model fits the facts. This may best be examined by using the observed values of p_{ij} to compare the actual numbers of occurrences of the various sequences of the three routine readings [*e.g.* (1, 0, 2), denoting category 1 on the first reading by the observer responsible for the survey, 0 on his second reading and 2 on the reading by the other observer] with the corresponding numbers which would be expected if the model were exact.* Details are given in Table 1, which shows the results obtained at five typical collieries, covering a wide range of prevalence of pneumoconiosis as found at the selected collieries. In view of the effect of random fluctuations the data corresponding to sequences for which the expected number of occurrences is very small have been pooled under the heading "All other sequences". The results indicate that the model does provide a reasonable "fit" to the observed data. There is a tendency for the observed numbers of films assigned to the sequences (0, 0, 1), (1, 1, 0), (1, 1, 2) and (2, 2, 1) to be slightly higher than the expected numbers. These sequences have in common the feature that the duplicate readings by the doctor responsible for the survey are consistent and differ from the single reading by the other doctor. The calculation of the expected numbers of films assigned to each of the sequences is based on the assumption that the three routine readings are independent. The tendency for the duplicate readings to be consistent points to the fact that there is a slight association between the first and second readings by the doctor who carries out the survey and that, in these circumstances, the hypothesis of independence is not strictly true.

* The probability of reading a film of true category i as (j, k, l) is given by the expression $p_{ij}^{(1)} \times p_{ik}^{(2)} \times p_{il}^{(3)}$, where $p_{ij}^{(1)}, p_{ik}^{(2)}, p_{il}^{(3)}$ refer to the reading probabilities on the first, second and third sets of routine readings.

Possibly the doctors tend to "remember" their previous readings on a small proportion of the "doubtful" films, although the second set of duplicate readings is generally carried out several months after the first. On balance, however, it is considered that this slight "memory effect" does not detract from the validity of the model, particularly in view of the fact that it is now the practice for only one routine reading to be made by the doctor responsible for the survey.

Viewed in the light of the requirements outlined earlier it is clear that the main criterion for an acceptable model is satisfied in that the results obtained by its application fit the facts reasonably well. With regard to the general assumptions involved in the model it is apparent that it does not provide an entirely realistic representation of the reading process on any particular film. This is a limitation, but in the circumstances it is impossible for a simple model accurately to represent the distinct processes involved in reading both simple and complicated pneumoconiosis. The third requirement, *i.e.* simplicity of conception and application, is also satisfied reasonably well. The calculations involved in the estimation of the reading probabilities are straightforward, although the use of a set of 36 values of p_{ij} to represent the performance by an observer on a particular batch of films is rather clumsy.

Applications of the "p_{ij}" Model

In spite of its limitations, the p_{ij} model is a useful concept and has a number of applications in a study such as the Pneumoconiosis Field Research. Some of these applications are illustrated below.

Comparison of Reading Standards.—The p_{ij} values corresponding to any particular set of readings provide a convenient summary of the observer's performance. A typical example is given in Table 2, which shows the p_{ij} values recorded on the three sets of routine readings (one by Observer A and two by Observer B) on the films obtained at one colliery. On this particular occasion there were considerable differences in the reading levels of the two doctors. The values of p_{oo} show that the probability of Observer A reading a category 0 film correctly was about 0·93, compared with the corresponding figures of 0·98 and 0·99 for Observer B's first and second readings. The probability of reading a category 0 film as category 1 was 0·07 on Observer A's reading and 0·02 and 0·01 on Observer B's first and second readings respectively. Comparison of other values of p_{ij} shows that Observer A tended, on this occasion, to read higher than Observer B throughout the whole range of simple pneumoconiosis. On the other hand, Observer B's first and second readings are in close agreement.

When dealing merely with different sets of readings on the same batch of films the tables of p_{ij} values are effectively equivalent to the more familiar "two-way" tables (Ashford, 1960), by which any two sets of readings may be compared. Even here, however, the use of probabilities rather than numbers of films is distinctly more helpful in the interpretation of the results.

When the p_{ij} values corresponding to readings on different batches of films are compared it is found that the differences from colliery to colliery are smaller than the differences between different sets of readings at the same colliery. In general, the variations do not appear to be directly related to variations in the distribution of abnormality, apart from a slight tendency for the values of p_{oo} to increase with increasing proportions of normal films. In this connexion it should be borne in mind that the p_{ij} values are a reflection of the variation of the readings on films of the same category. When the variation of the readings on all the films within a given batch is considered there is a definite tendency for the consistency to fall as the proportion of abnormal films increases (Ashford, 1960).

The Accuracy of the Individual Readings.—As the differences in the values of p_{ij} between the various collieries are relatively small it is considered that the results may profitably be combined for the purpose of any general examination of the film reading process. Details of the average p_{ij} values obtained

TABLE 2

"p_{ij}" VALUES CORRESPONDING TO THE ROUTINE READINGS AT A COLLIERY

i	j					
	0	1	2	3	4 (A)	5 (B, C, D)
(*a*) Observer A's Single Reading						
0	0·929	0·070	0·002			
1	0·027	0·689	0·284			
2		0·057	0·698	0·208	0·038	
3				0·885	0·115	
4 (A)					1·000	
5 (B, C, D)						1·000
(*b*) Observer B's First Reading						
0	0·981	0·019				
1	0·392	0·595	0·014			
2	0·019	0·170	0·755	0·057		
3			0·057	0·808		
4 (A)					1·000	
5 (B, C, D)						1·000
(*c*) Observer B's Second Reading						
0	0·989	0·011				
1	0·405	0·541	0·054			
2	0·019	0·170	0·755	0·057		
3			0·231	0·769		
4 (A)					1·000	
5 (B, C, D)						1·000

on the initial surveys at all the selected collieries are given in Table 3. These results are based on the analysis of about 100,000 film readings by the two doctors, and the p_{ij} values given refer to the average performance of the readers on films selected at random from a typical colliery population.

The highest standard of performance is obtained on films of category 0, on which 97% of the single readings are in agreement with the definitive classification. The corresponding figures for categories 1, 2, 3, 4(A) and 5(B, C, D) are respectively 63%, 69%, 79%, 77% and 90%. The majority of errors are of one category only, although there is an appreciable chance that films of definitive category A may be assigned to any of the other categories on a single reading.

It will be noted from Table 3 that there is a consistent tendency for the values (of p_{ij}) lying below the diagonal to be larger than the corresponding values (of p_{ji}) lying above the diagonal. For example, the values of p_{10} and p_{01} are respectively 0·250 and 0·029. This means that there is a chance of 250 in 1000 (or 1 in 4) that a film of true category 1 will be read as category 0 compared with a chance of only 29 in 1000 that a film of true category 0 will be read as category 1. This trend is a consequence of the fact that in the batches of films considered the numbers of films tend to decrease with increasing radiological category (Fig. 1). Thus, the majority of the "borderline" films in any given category lie on the lower boundary of the category and there is therefore a greater chance of assigning the film to a lower category rather than to a higher.

Investigation of Alternative Procedures for Assessing the Definitive Classification.—During the first three years of the Research the definitive classification was obtained on the basis of three sets of routine readings, two by the doctor responsible for the survey and one by the other doctor. A considerable amount of film reading was therefore involved, and as soon as a sufficiently reliable body of information about the errors associated with the film reading process had been built up it was decided to investigate the relative accuracy of the various alternative procedures. The following five possible methods of obtaining the definitive classification were examined.

TABLE 3

"p_{ij}" VALUES (BASED ON ROUTINE READINGS ON FIRST ROUND OF MEDICAL SURVEYS)

	j					
	0	1	2	3	4 (A)	5 (B, C, D)
0	0·970	0·029	0·001			
1	0·250	0·629	0·110	0·001	0·009	0·001
2	0·023	0·176	0·691	0·078	0·030	0·001
3	0·001	0·005	0·173	0·789	0·032	0·001
4 (A)	0·027	0·050	0·068	0·031	0·768	0·056
5 (B, C, D)	0·006	0·003	0·004		0·092	0·895

METHOD A.—Each film to be read once only by the Unit Medical Officer responsible for the survey and the "definitive" category to be assigned on the basis of this single reading. Under this procedure the need for classification by joint discussion would not arise.

METHOD B.—Each film to be read once by each of the Unit Medical Officers. If the two routine readings are consistent the common reading to be taken as "definitive". In any case of disagreement the film to be classified by joint discussion.

METHOD C.—Each film to be read three times, twice by the Unit Medical Officer responsible for the survey and once by the other Unit Medical Officer. If the three routine readings are consistent the common reading to be taken as "definitive". In any case of disagreement the film to be classified by joint discussion.

This corresponds to the procedure at that time in operation.

METHOD D.—Each film to be read three times, twice by the Unit Medical Officer responsible for the survey and once by the other Unit Medical Officer. If the three routine readings do not differ by more than one category the majority reading to be taken as "definitive". In any case of disagreement of more than one category the "definitive" classification to be assigned by joint discussion.

METHOD E.—Each film to be read three times, twice by the Unit Medical Officer responsible for the survey and once by the other Unit Medical Officer. If the three routine readings are all simple pneumoconiosis, the category nearest to the average reading to be taken as "definitive". If the three routine readings are all the same category of complicated pneumoconiosis the common reading to be taken as "definitive". If the readings include both simple and complicated pneumoconiosis, or more than one category of complicated pneumoconiosis, the film to be classified by joint discussion.

By the use of the p_{ij} model it is possible directly to determine the errors associated with the definitive category when this is derived straight from the routine readings. However, classification by joint discussion is involved in all methods except A, and it is therefore necessary to have some knowledge of the errors associated with joint classification. On the basis of the results obtained from a series of special reading sessions undertaken by the doctors it was estimated that about 80% of the readings by joint discussion (on the films selected for this method of classification) are correct (Ashford, 1957). This result has therefore been assumed for the purpose of comparing the methods. Details of the calculations

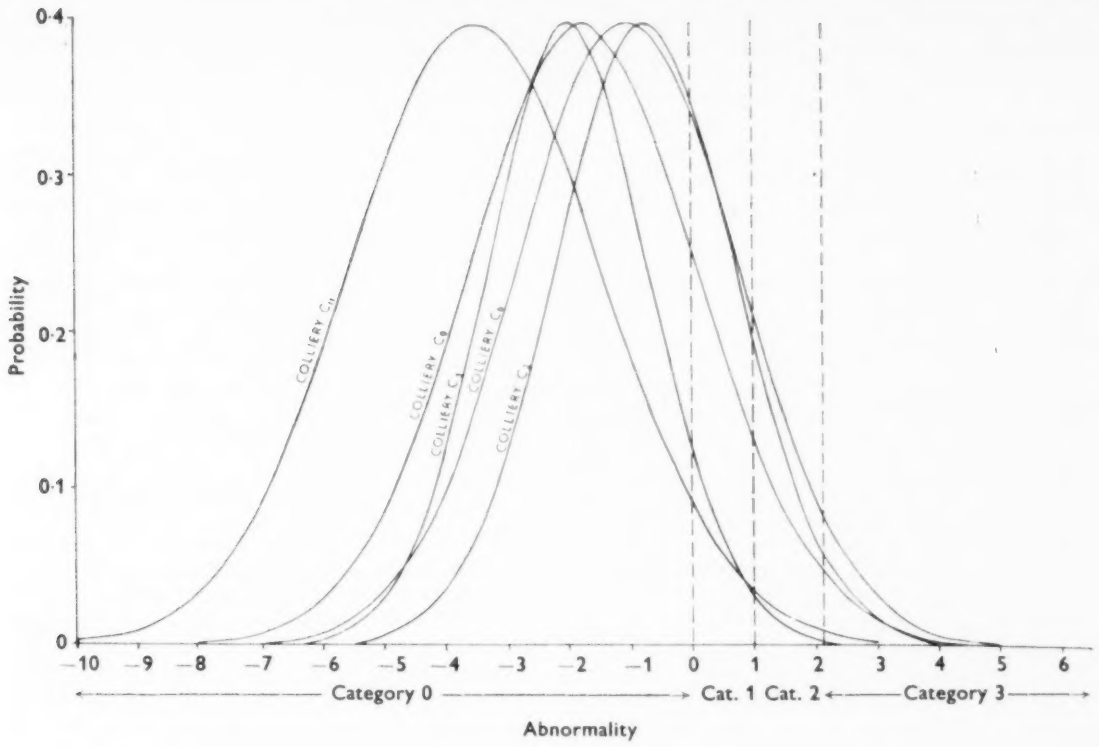


FIG. 1—Underlying distributions of abnormality.

involved are given in Appendix I and the proportion of films in the various categories which would be incorrectly classified on the definitive readings is given in Table 4. Method A involves a relatively high proportion of misclassifications but there is little to choose between methods B, C, D, and E. Method B involves the same number of readings by each doctor, as compared with methods C, D, and E, which involve two readings by one doctor and one by the other. Hence the introduction of a bias due to differences in standards between the readers is eliminated with method B, but not with the other three methods. For this reason it was decided to adopt method B on future surveys, in spite of the fact that it involves a slight loss of accuracy in comparison with some of the other procedures.

The "Improved" Model

Although the p_{ij} model was considered to provide a sufficiently good approximation to enable several urgent problems to be tackled in the early days of the Research, its limitations were recognized and further work was carried out in an endeavour to obtain a more exact representation of the reading process. In view of the fundamental differences in the criteria of diagnosis for simple and complicated pneumoconiosis it was felt that the next logical step was to consider each separately. Attention was therefore concentrated on the reading of simple pneumoconiosis only, on the grounds that the great majority of films belong to this category, and the improved model is concerned solely with this aspect of the problem.

Each radiograph may be regarded as being representative of a certain unique degree of ab-

TABLE 4

CLASSIFICATION OF RADIOGRAPHS
A COMPARISON OF FIVE DIFFERENT PROCEDURES
PERCENTAGE OF FILMS ASSIGNED TO AN INCORRECT "DEFINITIVE" CATEGORY

Method	No. of Routine Readings	"True" Category					
		0	1	2	3	A	B.C.D.
A	1	4	37	32	20	23	13
B	2	1	18	14	9	9	6
C	3	2	16	14	10	11	7
D	3	<1	18	13	8	9	5
E	3	<1	16	17	11	11	7

normality, which may be denoted the "true" abnormality of the film. For any given film this true abnormality value must be located at some point on a continuum, or abnormality scale, which covers the whole range of simple pneumoconiosis. It is perhaps unfortunate that the categories of simple pneumoconiosis have been labelled 0, 1, 2 and 3, as these numbers have no arithmetical significance in this context. The use of the numerical labels for the categories has led to the growth of a "tradition" by which it has become customary to regard category 0 as covering the range between 0 and 1 on the "natural" abnormality scale, category 1 as covering the range between 1 and 2, and category 2 as covering the range between 2 and 3. In this spirit it might seem logical to regard category 3 as lying between 3 and 4 on the scale, but some authorities (Wise, 1957) suggest that category 3 should extend upwards without limit from the point 3 on the abnormality scale. An abnormality scale of this kind is not an invalid one, but it has none of the desirable properties with which a more logically constructed scale of measurement is endowed.

When choosing a scale of abnormality to cover the subjective process of radiograph reading it is perhaps helpful to consider the design of an instrument for making an objective measurement. In a situation of this kind the scale of measurement is usually pre-defined (for example, a speedometer may be expected to give a reading in miles per hour). If it is required to make the measurement over a certain range, the instrument should be designed so that the readings in this range may all be made with equal accuracy, and so that, if there is any systematic bias, this will be constant at all points throughout the range. In the case of the speedometer the degree of "needle wobble" and "drift" should be the same at all speeds. In reading radiographs the situation is reversed. The "instrument" (represented by the reader) is pre-defined, in the sense that there is little chance of making a fundamental change in the performance of an experienced reader (provided, of course, no deliberate attempt is made to do so) but the scale of measurement may be varied at will. However, the basic requirement is the same, in that the bias and variability of the readings by any particular observer should remain constant at all points along the scale of measurement. Unfortunately, there is no reason why the "traditional" scale described above should have these properties.

Thus, the first requirement for an improved procedure is to choose the scale of abnormality in such a way that, whatever the true abnormality value of a film, the observer's readings will be distributed about this value with constant bias and variability. In mathematical terms this means that if the true abnormality value of the film is x, the readings by an observer on the film will be distributed with mean $x + b$ and variance σ^2 where b and σ^2 represent respectively his reading bias and variability and are constant at all points of the scale. Now, the process of film reading involves the consideration and interpretation of a large number of different aspects of the film, and on these grounds it seems reasonable to require that the error distribution should be normal (Gaussian), as is commonly found in the case of objective measurements of all kinds made under similar circumstances. In other words, the scale of abnormality should be chosen in such a way that the readings on any particular film are normally distributed about the true abnormality value of the film, with constant bias and variability at all points along the scale.

The data available for consideration consist of the three sets of routine readings and the definitive readings at each colliery. These sets of readings may be regarded as resulting from the superposition of the error distribution associated with the performance of the observer, at the time the readings were made, upon the "true" distribution of abnormality at the colliery concerned. Examination of the definitive and routine readings obtained at the selected collieries shows that it is possible to choose the position of the boundaries between the categories in such a way that the observed distributions are approximately normal. This means that for each set of readings the result of superimposing the error distribution on the true distribution is a normal distribution. It was therefore decided to test as a first step the hypothesis that the true distributions are also normal. Experience has shown that many characteristics of the mining populations under consideration follow a normal distribution and the assumption that the true distributions of radiological abnormality at the various collieries are also normal is not an unreasonable one. On this hypothesis the true distribution of abnormality at a colliery can be described in terms of two parameters, the mean m and the variance s^2, and the distribution of observations on any particular set of routine readings (which represents a normal error distribution superimposed on a true normal distribution) has mean $(m + b)$ and variance $(\sigma^2 + s^2)$.

For practical purposes, the readings are made in terms of four discrete categories which together cover the whole of the range of abnormality, and the choice of a scale of measurement resolves itself into the selection of suitable positions for the category boundaries. As the lowest category of simple pneumoconiosis is category 0 and the highest is category 3 it is reasonable to take the lower

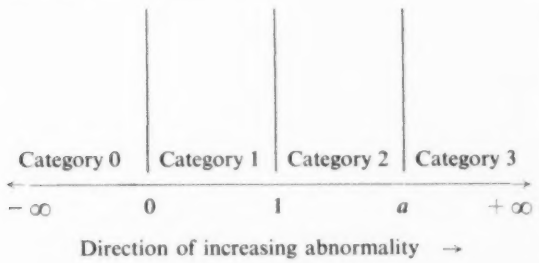
TABLE 5

TEST OF THE "IMPROVED" MODEL WITH THE OBSERVED DATA
NUMBERS OF OCCURRENCES (OBSERVED AND EXPECTED) OF THE VARIOUS SEQUENCES OF ROUTINE READINGS
(Simple Pneumoconiosis Only)

Colliery	C_2		C_6		C_9		C_3		C_{11}	
Sequence	Observed	Expected	Observed	Expected	Observed	Expected	Observed	Expected	Observed	Expected
(0, 0, 0)	361	358	436	468	1,337	1,359	1,336	1,366	1,167	1,164
(0, 0, 1)	21	23	5	3	46	45	56	47	24	21
(0, 1, 0)	43	35	37	33	12	16	15	17	5	4
(1, 0, 0)	18	14	28	22	16	13	13	16	9	7
(0, 1, 1)	19	19	4	7	13	15	11	12	3	6
(1, 0, 1)	4	8	2	3	9	9	6	9	5	8
(1, 1, 0)	36	26*	43	30*	32	24	36	16*	5	3
(1, 1, 1)	28	36	18	20	54	50	27	23	13	13
(1, 1, 2)	16	13	4	2	23	19	11	9	7	6
(1, 2, 1)	11	16	12	13	7	7	3	3	0	1
(2, 1, 1)	5	7	3	8*	0	5*	1	3	0	2
(1, 2, 2)	11	12	9	4*	10	8	2	3	0	2
(2, 1, 2)	8	5	2	2	2	4	2	2	1	3
(2, 2, 1)	13	14	21	16	18	10*	4	3	4	1*
(2, 2, 2)	21	23	30	12*	33	25	10	5*	8	6
(3, 3, 3)	13	15	8	11	11	14	2	1	3	3
All others	53	56	35	44	31	30	17	16	9	6

* Value of χ^2 in excess of 3·0.

boundary of category 0 as $-\infty$ and the upper boundary of category 3 as $+\infty$. The location and dimensions of the abnormality scale are arbitrary, in the sense that it is possible to choose any convenient zero or origin and any convenient scaling factor. This means that two of the remaining three category boundaries can be located at arbitrary points on the scale. For convenience, the boundary between categories 0 and 1 may be chosen to be zero and that between categories 1 and 2 to be unity. Only the boundary (denoted "*a*") between categories 2 and 3 then remains to be determined from the data. Thus the scale of abnormality is



The mathematical techniques employed to determine the position of the boundary between categories 2 and 3 for the subsequent estimation of the various parameters are based on the method of maximum likelihood and have been described in detail elsewhere (Ashford, 1959). Briefly, the procedure has been, first, to derive the best estimate of *a* from the analysis of the definitive reading distributions recorded for all the collieries. This analysis indicates that the boundary between categories 2 and 3 should be located at the point, $a = 2{\cdot}12$. Next, the model so derived is used to estimate the parameters associated with the underlying abnormality distributions and with the various error distributions in terms of the number of occurrences of the different sequences of all routine readings. Finally, the validity of the model can be tested by comparing the "predicted" numbers of sequences of readings with the actual numbers obtained at individual collieries. The "fit" of the model to the data from five collieries is illustrated at Table 5. The calculations necessary for a satisfactory treatment of the data are complex and a complete solution has been obtained at only these five collieries. However, as they represent a good cross-section of the range of prevalence found at all the selected collieries, they may be taken to provide a reliable test of the general application of the procedure. It will be seen that the results obtained using the model are, in general, in close agreement with the observations. The number of the discrepancies is no greater than would be expected to occur by chance, although (as in Table 1) there is evidence of a slight "memory effect", in that the observed numbers of films assigned to the sequence on which the duplicate readings by the same doctor are consistent tend to be higher than the predicted numbers. This confirms the deduction from the earlier model that there is a slight association between the first and second readings by the doctor who carried out the survey. However, as with the earlier model, this "memory effect" does not detract from the validity of the new model for the study of observer variation. Indeed the model as enunciated applies only to a single reading on a film, and the

observed association between duplicate readings is a secondary consideration. Comparison of the results in Table 5 with those in Table 1 shows that the general level of agreement is better with the new model than with the old.

Applications of the "Improved" Model

As with the older, p_{ij}, model, the new model has a number of useful applications in the study of radiograph reading procedures and observations, and some of these applications are illustrated below.

Underlying Distributions of Abnormality.—It has been found that, provided the scale of abnormality is suitably chosen, the data are consistent with the hypothesis that the underlying abnormality at a colliery follows a normal distribution and may therefore be defined in terms of only two parameters —the mean and standard deviation. The distributions at the five collieries considered in detail may be compared in Fig. 1, and the corresponding means and standard deviations are given in Table 6. The means have been estimated from the definitive reading distributions (as these are considered to be effectively free from bias), and the standard deviations are derived from the analyses in terms of the number of occurrences of the various sequences of routine readings. The distribution curves are then plotted by reference to tabulated values of the standard normal distribution, and a simple picture is obtained of the distribution of abnormality at the particular colliery.

TABLE 6

UNDERLYING DISTRIBUTIONS OF ABNORMALITY

Colliery	Mean	Standard Deviation
C_2	−0·73	1·49
C_8	−1·05	1·79
C_9	−1·72	1·89
C_5	−1·99	1·33
C_{11}	−3·53	2·03

The Accuracy of a Single Reading.—Under the new model it has been shown that the performance of an observer on a particular set of readings may be described in terms of two parameters, his bias and his variability. The corresponding figures for the three sets of routine readings at the five collieries are given in Table 7, where the figures for bias refer to the appropriate doctor's standard relative to the definitive readings.

The salient feature of these results is the general tendency for Observer B to read higher than Observer A. With the exception of Observer B's readings at Colliery C_2 the reported biases on the first and second readings by the doctor responsible for the survey are in close agreement. It is also apparent that the second set of readings by the doctor responsible for the survey are generally less variable than the first. Both the sets of readings by the doctor responsible for the survey tend to be less variable than the readings by the other doctor.

TABLE 7

READING ERRORS

Colliery (Surveyed by Observer A)		C_2	C_8	C_{11}
Bias (b)	Observer A (1st reading)	−0·44	−0·08	0·14
	Observer A (2nd reading)	−0·36	−0·03	0·08
	Observer B	−0·39	−0·07	0·40
Standard error (σ)	Observer A (1st reading)	0·31	0·37	0·42
	Observer A (2nd reading)	0·21	0·33	0·35
	Observer B	0·63	0·72	0·46
Colliery (Surveyed by Observer B)		C_5	C_9	
Bias (b)	Observer B (1st reading)	0·13	−0·14	
	Observer B (2nd reading)	0·35	0·02	
	Observer A	0·09	−0·60	
Standard error (σ)	Observer B (1st reading)	0·41	0·52	
	Observer B (2nd reading)	0·42	0·44	
	Observer A	0·67	0·47	

Besides providing a very convenient summary of standards for any given set of readings the new model enables account to be taken of the variation in the chance of misclassification within the category. This is illustrated in Fig. 2, which refers to the three sets of routine readings at Colliery C_{11}. For each set of readings a series of four curves shows the chance of reading a film of any given degree of abnormality as category 0, 1, 2 and 3 on each of the routine readings.

As the abnormality value increases from the lower limit of category 0 the chance that Observer A's first reading is category 0 decreases from unity below about −1·3 to 0·8 at −0·5, 0·4 at 0, 0·1 at 0·5 and approaches zero beyond about 0·9. The chance of Observer A's calling a film category 1 on his first reading increases from zero below about −1·3 to 0·6 at 0, reaches a maximum of 0·76 at 0·4, and then falls away to 0·4 at 1·0, being effectively zero again beyond about 2·0. The category 2 curve shows a similar pattern, although the maximum of 0·82 at 1·5 is slightly higher than that for category 1 (because category 2 covers a greater range of abnormality). The curve for category 3 increases from zero below about 0·8 to 0·6 at the boundary between categories 2 and 3, and approaches unity beyond about 3·0. At any one point on the scale of abnormality the sum of the ordinates of the four curves is unity, as the film must be assigned to some category. Thus the majority of reading errors are of one category only, although in a small number

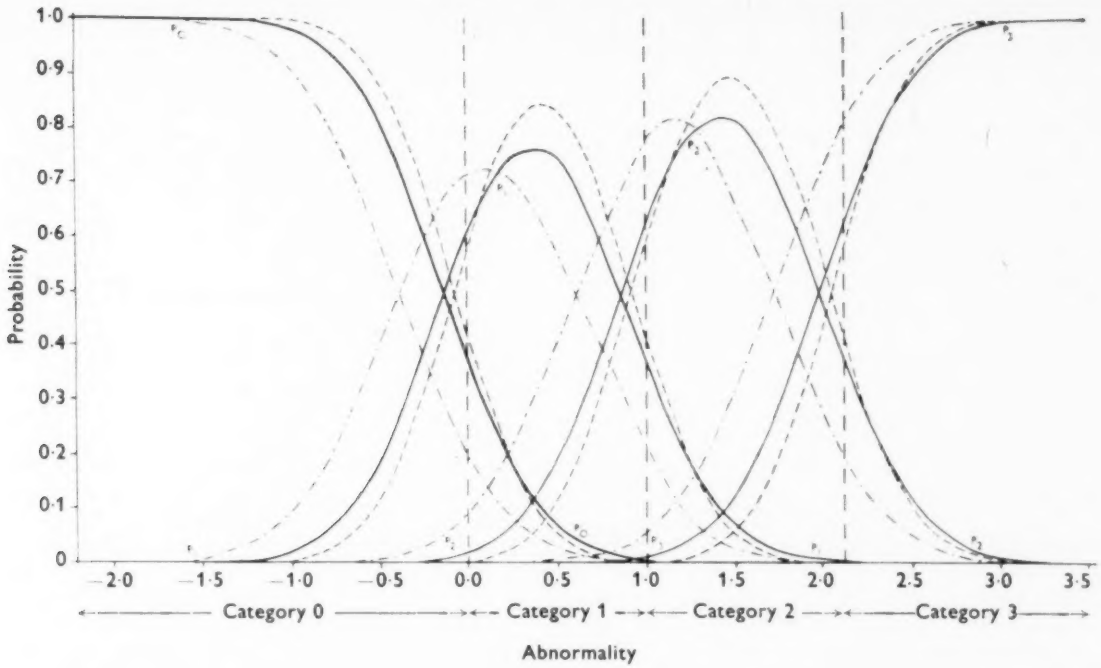


FIG. 2.—Colliery C_{11}. Accuracy of the three sets of routine readings. First reading by Observer A ————————; second reading by Observer A – – – – – –; reading by Observer B —— – —— – ——; P_0 = Probability of reading of category 0; P_1 = Probability of reading of category 1; P_2 = Probability of reading of category 2; P_3 = Probability of reading of category 3.

of cases differences of two categories may be recorded. The probability curves for Observer A's second reading are very similar to those for his first reading. The peak values for the category 1 and category 2 curves are higher, reflecting the smaller variability of the second reading. The four curves relating to Observer B's readings are displaced to the left of those for Observer A. This is a reflection of the tendency for Observer B to read higher than Observer A, which makes the chance of his reading a film as category 0 smaller and increases the chance of his reading a film as category 1, 2 or 3.

It is interesting to note that the chance of reading a film with abnormality value of less than about —2·0 as anything other than category 0 is negligible. Similarly, virtually all the films with abnormality values greater than 3·5 will be read as category 3 The chance of misclassification increases as the abnormality value approaches the category boundary, but even in the middle of categories 1 and 2 an appreciable proportion of the routine readings will be incorrect.

The Accuracy of the Sequences of Routine Readings.—It has been shown that the chance of assigning a film to any given category on a single routine reading depends both on the "true" abnormality value of the film and also on the reading error relating to the particular set of readings. Similarly, the chance of obtaining any given sequence of routine readings is a function of the true abnormality value and of the three sets of reading errors. The variation in the probabilities of obtaining the various sequences of routine readings is illustrated in Fig. 3, which also refers to colliery C_{11}.

The chance of obtaining the sequence (0, 0, 0) decreases from unity for abnormality values below about —2·0 to 0·5 at —0·5, 0·03 at 0, and approaches zero beyond about 0·25. It will be noted that a proportion of the films in the lower part of category 1 will be read as (0, 0, 0). The curves for the sequences (1, 0, 0), (0, 1, 0) and (0, 0, 1) differ significantly both in position and shape, owing to the differences in standards on the three sets of readings. The maxima lie towards the upper limit of category 0, although they occur at slightly different points on the scale. It should, however, be noted that the curves themselves cover a considerable range of abnormality values and that, for example, there is a chance of at least one in 20 of obtaining a reading

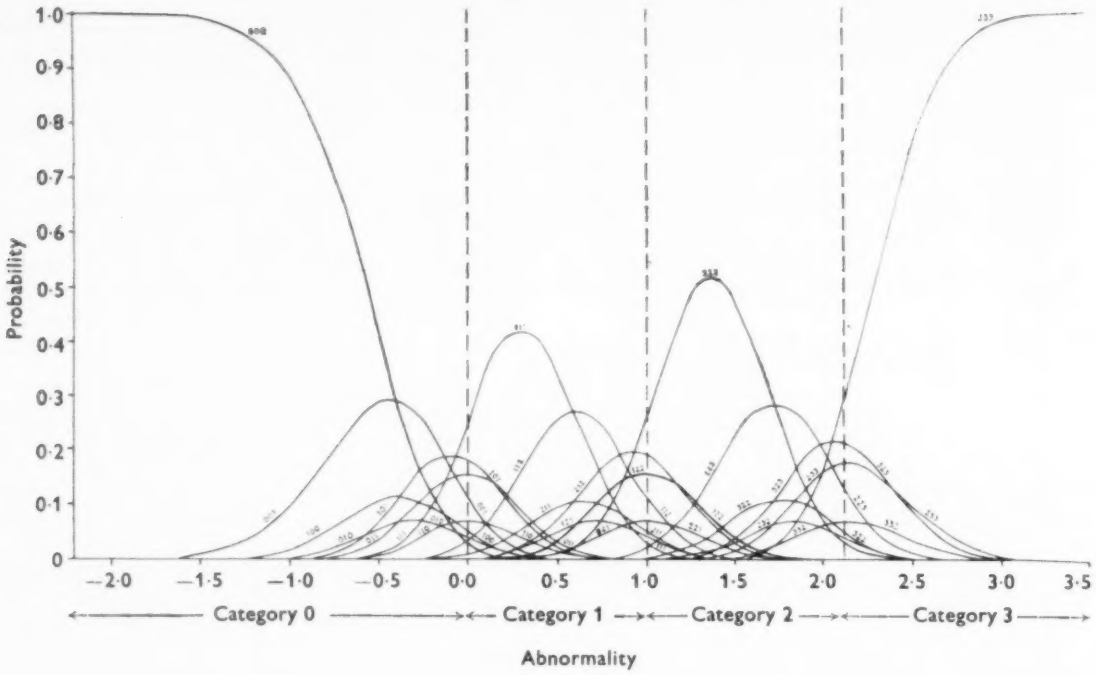


FIG. 3.—Colliery C_{11}. Accuracy of the various sequences of routine readings.

of (0, 0, 1) between the points −1·2 and 0·2 on the abnormality scale. The curves corresponding to the sequences (0, 1, 1), (1, 0, 1) and (1, 1, 0) follow a similar pattern, although they are displaced to the right. The curve corresponding to the sequence (1, 1, 1) rises from zero for abnormality values below about −0·7, to a maximum of just over 0·4 at 0·35, and decreases to zero again beyond about 1·3. The curve corresponding to the sequence (2, 2, 2) is similar to that for category 1 but attains a maximum of just over 0·5.

Test of an "Averaging Procedure" to obtain the Definitive Classification of a Film.—The results given in Fig. 3 also serve as a warning against the indiscriminate application of any form of "averaging procedure" for the assessment of the definitive classification. The marked differences between the probability curves for sequences such as (1, 0, 0), (0, 1, 0) and (0, 0, 1) emphasize the danger of regarding all sequences of category 0 twice and category 1 once as being representative of the same abnormality distribution. Even if the reading errors were constant on the three sets of routine readings (no bias, constant variance), in which case the curves for the sequences (1, 0, 0), (0, 1, 0) and (0, 0, 1) would be coincident, the (0, 0, 1) probability distribution would depend on the reading variance on the particular batch of films. On another batch of films, again with constant reading errors, the (0, 0, 1) probability distribution would again depend on the reading variance, which might well be different from that on the first. Thus, even if the reading errors on the same batch of films were constant (which is most unlikely), readings of, say, (0, 0, 1) on different batches of films would not necessarily be comparable. In summary, therefore, although a sequence of readings of the form (0, 0, 1) does indicate on the average that the film is representative of a greater degree of abnormality than one read as (0, 0, 0), it would be necessary to take account of the reading errors on each set of routine readings before any quantitative use could be made of this information. As to whether or not a film read as (0, 0, 1) is actually to the left or right of the boundary between categories 0 and 1, which is the major question both for progression studies and for statements of prevalence, reference to Fig. 3 shows that there is an appreciable chance of such a film belonging to either category. In this particular instance a great proportion of the films read as (0, 0, 1) belong to category 0, but it would obviously

be wrong to assign all such films to this "average" reading.

It is perhaps worth emphasizing that the example dealt with in this section refers to the averaging of two readings by one observer and one by another. It will be quite obvious, however, that the argument applies equally well to any other method of averaging independent readings by two or more observers.

Discussion and Conclusions

The above illustrations show that the new model has a number of advantages. In the first place it can be applied to any particular film, provided the distribution of reading errors is known, as due account is taken of position on the abnormality scale within the category. The application of the model suggests that if a film is on the boundary between two categories it is equally likely to be read as either (if the reading bias is zero), and that as the true abnormality value moves away from the boundary the chance of misclassification decreases. In short, the new model gives a realistic representation of the actual mechanism of the reading process. From the point of view of simplicity of conception, once the initial difficulties over the choice of a scale of abnormality have been overcome, the description of the observer's performance in terms of only two parameters (his bias and variability) is obviously preferable to the multiplicity of p_{ij} values implicit in the older model.

On the other hand the greater realism and simplicity of conception of the new model are obtained at the expense of a loss of universality of application, as the approach is confined to simple pneumoconiosis only. This is, of course, inevitable as the reading of simple pneumoconiosis and P.M.F. are completely separate processes. There is a further theoretical disadvantage, in that the model implies that the observer's bias is of the same "sign", *i.e.* either positive or negative, over the whole range of abnormality. For example, it is tacitly assumed that if he is "reading high" on the boundary between categories 0 and 1 he is also "reading high" on the boundaries between categories 1 and 2 and between categories 2 and 3. Now, it seems reasonable to suppose on general grounds that a definite bias on a particular set of readings is really due to the observer having drawn the borderlines between the categories at the wrong points on the scale of abnormality, and there is no theoretical reason why he should make the same kind of mistake on each of the three boundaries, although in the five examples considered this appears to have been the case. This difficulty is avoided in the p_{ij} model, as each category boundary is considered separately.

The major practical disadvantage of the new model is the extent of the computations required to analyse the results in a satisfactory manner. The time taken to carry out the analysis is, in fact, comparable with the time taken for the readings. Analysis of our data shows that the "fit" of the new model is better, but not a great deal better, than that of the original model, and while the more realistic nature of the new model is an advantage, particularly from the point of view of the film reader, this cannot be measured in objective terms.

On balance, therefore, it appears that both models are of use and have particular applications, the one chosen depending upon the requirement of the research worker and the facilities available for computational work. Within the Pneumoconiosis Field Research the "improved" model has been used to a limited extent to explore some of the more interesting and obscure features of film reading and classification. On the other hand, its application to some of the more routine analyses of the results obtained at the selected collieries has not been considered justified, on the grounds of the extra computations involved. For example, in a companion paper, describing the analysis of all the film readings from the medical surveys conducted in the first six years of the research, the p_{ij} model has been used as the basic method of approach, although, for the sake of simplicity of presentation, the results have been illustrated in the shape of orthodox "two-way" tables (Ashford, 1960).

This paper is published by permission of the National Coal Board, but the views expressed are not necessarily those of the Board. The work described is part of the Board's Pneumoconiosis Field Research.

Our thanks are due to Drs. S. Rae and P. J. Chapman, who read the films and provided constructive advice and criticism, and to Dr. J. Rogan and Mr. D. Hicks for their constant encouragement.

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APPENDIX I

Calculation of the Accuracy of the Definitive Classification

Method A.—The proportion of films of "true" category i, which are assigned to an incorrect "definitive" category, is given directly by $(1-p_{ii})$.

Method B.—When a film is classified under this procedure there are three possibilities: (*a*) the two routine readings will be consistent and correct, (*b*) the two routine readings will be consistent but incorrect (in which case the film will be assigned to an incorrect "definitive" category), or (*c*) the two routine readings will be inconsistent (in which case the film will be classified by discussion). For a film of true category i the probabilities are given below:

Routine Readings	Procedure	Probability
Consistent and correct	No discussion	p_{ii}^2
Consistent but incorrect	No discussion	$\sum_{i \neq j} p_{ij}^2$
Inconsistent	Discussion	$1-\sum_{j} p_{ij}^2$

Hence the probability of a film being assigned to an incorrect "definitive" category is

$$\sum_{i \neq j} p_{ij}^2 + 0{\cdot}2 \left(1 - \sum_{j} p_{ij}^2\right).$$

Method C.—By a similar argument to that described above it can be shown that the probability of an incorrect "definitive" reading is $\sum_{i \neq j} p_{ij}^3 + 0{\cdot}2 \left(1 - \sum_{j} p_{ij}^3\right)$.

Method D.—Under this procedure a film of "true" category 0 will be assigned to the correct "definitive" category without discussion for routine readings of 0, 0, 0; 1, 0, 0; 0, 1, 0, and 0, 0, 1, the film will be assigned to an incorrect "definitive" category without discussion for routine readings of 0, 1, 1; 1, 0, 1; 1, 1, 0; 1, 1, 1, and other sequences differing by only one category which occur with a very low probability; the film will be discussed for routine readings of 0, 1, 2; 0, 2, 1; 1, 0, 2; 1, 2, 0; 2, 0, 1; 2, 1, 0, and other sequences differing by more than one category which occur with a very low probability.

The corresponding probabilities are respectively

$p_{00}^3 + 3\,p_{00}^2\,p_{01}$; $3\,p_{01}^2\,p_{00} + p_{01}^3 + \ldots$,

and; $6\,p_{00}\,p_{01}\,p_{02} + \ldots$

The probability of classifying a film of "true" category 0 incorrectly is thus $[3\,p_{01}^2\,p_{00} + p_{01}^3 + \ldots + 0{\cdot}2\,(6\,p_{00}\,p_{01}\,p_{02}) + \ldots]$.

By a similar method it is possible to calculate the corresponding probabilities for the other true categories.

Method E.—The calculations are very similar to those for Method D, the main difference being the fact that films which differ by more than one category of simple pneumoconiosis are not discussed.

Brit. J. industr. Med., 1960, **17**, 293.

THE CLASSIFICATION OF CHEST RADIOGRAPHS FOR COALWORKERS' PNEUMOCONIOSIS

A STUDY OF THE PERFORMANCE OF TWO READERS OVER A PERIOD OF SIX YEARS

BY

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The paper is concerned with the performance over the past six years of the two doctors responsible for the classification of chest radiographs obtained by the National Coal Board's Pneumoconiosis Field Research. A brief description is given of the categories of pneumoconiosis used in the Research and of the procedures adopted to decide the final or "definitive" classification. The readings obtained are then considered in detail and three main points emerge from the analysis. First, it is shown that there have been marked systematic fluctuations in the reading levels of these two very experienced observers. In spite of these individual variations it is found that the standards applied on the definitive readings, which are based on the joint discussion by the two doctors of films on which their individual readings are inconsistent, remain remarkably constant over a period of several years. The third main feature of the analysis is the considerable differences in the magnitude of the reading errors between the various categories of pneumoconiosis. It is concluded that, although the existing procedures provide a satisfactory way of estimating the prevalence of pneumoconiosis, it would be desirable to increase the number of film readers. The beneficial effect of the system whereby a running check is kept on film reading standards is also established.

As part of the National Coal Board's Pneumoconiosis Field Research (Fay, 1957), periodic medical surveys are carried out at the selected collieries at intervals of about four years. These surveys have been in progress since late 1953. Up to the present time the initial medical examinations have been completed at the 26 collieries* associated with the Research, and follow-up examinations have been completed at five collieries. One of the most important components of the medical surveys is the taking and subsequent classification of a 14 in. × 14 in. postero-anterior chest radiograph for each man presenting himself for examination. There are two mobile chest radiography units, which respectively cover the collieries in the north and south of the country, and each is in the charge of an experienced doctor. Every film is classified at least once by each of the two doctors and these readings, of which more than 100,000 have been made during the past six years, provide what is probably a unique body of information about the performance of two experienced film readers over a long period of time.

Classification of Films

The categories of pneumoconiosis used in the medical surveys are those currently accepted by international agreement (International Labour Office, 1953), which recognizes the distinction between simple and complicated pneumoconiosis or progressive massive fibrosis (P.M.F.).† Simple pneumoconiosis is subdivided on a quantitative basis into three categories, increasing in degree of abnormality, and numbered 1-3, category 0 being reserved for films which are within normal limits. Films showing evidence of complicated pneumoconiosis are separately classified into four categories —A, B, C and D.

In view of the considerable element of doubt associated with a single reading of pneumoconiosis,

* In 1958 one of the original 25 selected collieries was closed and it was subsequently replaced by another colliery in the same coalfield.

† The classification of P.M.F. by the Pneumoconiosis Field Research has subsequently been revised, in the light of recent experience.

even by an experienced radiologist (Fletcher and Oldham, 1949), the final classification of the radiographs is based on a series of readings by both doctors (Observers A and B). During the period under consideration three different procedures have been applied for this purpose as follows.

(a) In the first place each film was read independently on three occasions, twice by the doctor responsible for the survey and once by the other doctor. When these three "routine" readings did not differ by more than one category* and where there was no suggestion of other disease which would complicate the pneumoconiosis readings, the final or "definitive" classification was assigned on a majority basis. For all other films the definitive classification was assigned as a result of joint discussion between the two doctors. This procedure was applied at the first two collieries examined (C_1 and C_2) but was subsequently modified to guard against the possibility that the definitive readings might be disproportionately affected by the performance of the doctor responsible for the survey.

(b) On the first medical surveys at collieries C_3-C_{24} the method of final classification by joint discussion was extended to all films on which the three routine readings were not consistent.

(c) The second change in film reading procedures took place as a result of a special study of the accuracy of the joint reading procedure (Fay and Ashford, 1960). On the basis of this investigation it was decided to discontinue the second reading by the doctor responsible for the survey and to base the definitive classification on a single reading by each observer, together with the joint discussion of disagreements. To obtain a check on the consistency of reading, a repeat classification by the doctor responsible for the survey was carried out on a random one in 10 sample of films. This revised procedure was applied on the first surveys at collieries C_{25} and C_{26} and on the second round of surveys at all collieries so far examined.

The second survey films are at present classified without reference to any film or films of the same man obtained on the first survey.† To obtain a comparison of the reading levels on successive surveys at the same colliery, a random one in 10 sample of first survey films, selected mainly from those on which there were disagreements on the first survey,‡ is intermixed with the second survey films and classified again, according to the standard procedures.

During the first round of medical surveys the various sets of readings at a colliery extended over a period of as long as a year and it was impossible to provide the doctors with up-to-date information about their current reading levels. On the second round of surveys, however, a running check was kept on the doctors' performance and as far as possible each survey was completed and the results were analysed and discussed before the next survey was undertaken.

Distribution of Abnormality at the Various Collieries

It is apparent on general grounds that the level of agreement between repeat readings by the same observer or between single sets of readings by different observers in terms of the standard categories of pneumoconiosis will depend on the amount of abnormality in the batch of films being classified, as well as on the standard of performance of the observers. For example, a batch containing a higher proportion of "normal" films (most of which will be assigned to category 0 on each set of readings) will be read more consistently than a batch containing a lower proportion of such films. Thus, in any realistic study of reading errors it is essential to take account of the distribution of abnormality in the films on which the results are based. A more detailed quantitative treatment of the problem (Ashford, 1959) lends further support to this conclusion.

There is a wide variation in the prevalence of pneumoconiosis at the selected collieries on the first medical surveys. The percentages of men assigned to category 0 lie mainly between 72·5 and 95·0, although figures of less than 70% were recorded at four collieries. The proportions classed as category 1 vary from 2·5 to 17·5%, with the majority lying between 5·0 and 15%, and the proportions classed as category 2 tend to be slightly lower. At all except five collieries less than 2·5% of the population were classed as category 3 and at all except three, less than 5% were classed as P.M.F. On average, approximately 82% of films were classed as category 0, 10% as category 1, 5% as category 2, 1% as category 3 and 2% as P.M.F. on the definitive readings. At collieries where the second medical surveys have been carried out the results obtained are similar to those recorded on the corresponding first surveys.*

Consistency of the Duplicate Readings by the Same Observer

A measure of the error associated with the film reading process may be obtained by comparing

* Readings of simple and complicated pneumoconiosis on the same films were considered to differ by more than one category.

† Studies of the relative merits of side-by-side and independent classification of the films of the same man on successive surveys are currently in progress.

‡ At Collieries C_1-C_3 the sample consisted entirely of the disagreement films. At Collieries C_4 onwards a quarter of the sample consisted of films on which the first survey readings were consistent.

* It should be borne in mind that, due to labour turnover, there may be appreciable differences in the populations examined at a colliery on successive surveys.

TABLE 1

FIRST SURVEY AT COLLIERY C_6: DUPLICATE READINGS BY OBSERVER B

No. of Films

Second Reading \ First Reading	0	1	2	3	A	B, C, D	All
0	441	30					471
1	41	65	12		1		119
2	1	29	57	3	1		91
3			2	16	1		19
A					21	1	22
B, C, D						5	5
All	483	124	71	19	24	6	727

Percentage of consistent readings 83·2

duplicate readings carried out by the doctor responsible for the survey. At any given colliery these results may conveniently be expressed in terms of a "two-way" table and a typical example is given in Table 1, which refers to the readings by Observer B at colliery C_6. The differences between the two sets of readings are revealed in tables of this kind by the number of films in the "off-diagonal" positions. For example, a total of 30 films was read as category 1 on Observer B's first reading and as category 0 on his second, whereas 41 of the films read as category 1 on his second reading had been read as category 0 on his first reading. The differences in successive readings may be attributed to two distinct sources of error. In the first place there may be systematic differences in the placing of the various category boundaries on the two sets of readings, which will be indicated by corresponding differences in the marginal totals. On this particular batch of films Observer B tended to read higher (*i.e.* to read more abnormality) on the second set of readings than on the first, particularly on the boundary between categories 1 and 2, and statistical tests* show that this difference is significant. The second source of error is the variability of the reading process itself, which leads to different results between two sets of readings even when there is no change in average reading levels. The combined effect of the two sources of error on Observer B's readings on colliery C_6 was that different duplicate readings were recorded on 16·8% of the films. As is generally found, almost all the disagreements were of one category only.

* In this context the testing of the significance of the difference in average reading levels on the first and second occasions is based on the assumption that, if the same standard were applied on both sets of readings, the expected number of films in any particular position in the two-way table above the diagonal must be equal to the expected number of films in the corresponding position below the diagonal.

Details of the percentage of consistent duplicate readings on the first survey films at all collieries and on the second survey films at the first five collieries so far examined are given in Fig. 1, where these results have been plotted against the percentage of men classed as category 0 on the corresponding set of definitive readings. In this figure a distinction has been made between the two doctors and between the first and second survey readings. As might have been expected on general grounds the proportion of consistent readings shows a marked tendency to increase with increasing proportions of "normal" films in the batch, from 77% at a colliery with just less than 60% of normal films to more than 97% at a colliery with more than 95% of normal films. There are, however, considerable differences in the levels of consistency at collieries with similar distributions of abnormality, which suggest that other factors (such as systematic differences in reading levels or in the technical quality of the films) are also involved. The percentages of normal films at the collieries surveyed by Observer A tend to be higher than those at the collieries surveyed by Observer B and the consistency of his readings is correspondingly greater. On the whole, the second survey readings at a colliery are more consistent than the corresponding first survey readings.

When the average levels of classification applied by Observer A on his duplicate readings on the first survey films are compared, there is no evidence of any significant difference in his standards on seven of the 12 surveys for which he was responsible. At the remaining five collieries his second reading was significantly higher than his first. Observer B was responsible for the first surveys at 14 collieries and at four of these there was no significant difference between his first and second readings. At seven of the remaining 10 collieries his second reading was

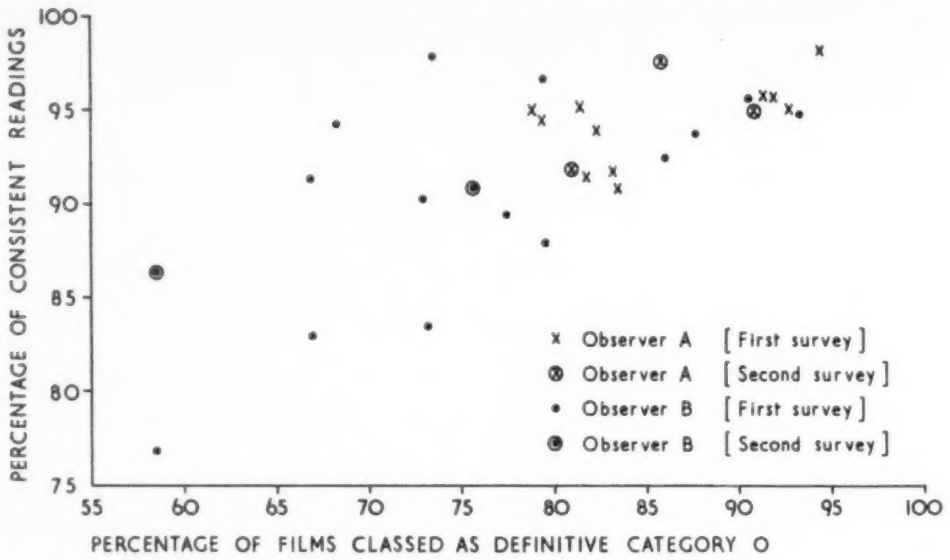

FIG. 1.—Relationship between amount of abnormality and percentage of consistent duplicate readings by the same Observer.

significantly lower than his first and at the other three collieries his second reading was significantly higher.

On the first round of surveys the readings of the films obtained at any one colliery extended over a period of as long as a year and the observed differences between the duplicate readings thus reflect periodic fluctuations in average standards of performance. It is, however, interesting to note that at all collieries where the differences between Observer A's duplicate readings were significant he tended to read higher on the second reading than the first. This trend may well be associated with the fact that the first set of readings forms the basis for any immediate medical advice which may be given to the subject. On the second round of surveys the duplicate readings are made within a comparatively short space of time and at the five collieries for which results are so far available there have been no significant differences between the corresponding sets of readings.

Consistency of the Readings by Different Observers

As it appears from a study of the duplicate readings that the standards of classification of a single observer may vary in time, the direct comparison of the readings by different observers is subject to some uncertainty. For example, if the doctor responsible for the survey at a colliery has adopted different standards on his duplicate readings, it is possible that the readings by the other doctor may differ significantly from one set but not from the other. For this reason it is more convenient to compare each set of routine readings individually with the best available estimate of the true position. In a subjective process such as radiograph reading there can be no absolute standards and the most reasonable substitute is provided by the definitive readings, which (except at collieries C_1 and C_2) represent the agreed opinion of both observers. The use of the definitive readings for this purpose is supported by the results of a detailed quantitative study of the film reading process (Fay and Ashford, 1960), which shows that the proportion of films assigned to an incorrect definitive category is small.

Each set of routine readings may be conveniently compared with the corresponding definitive readings in terms of a two-way table, and a typical example is given in Table 2, which refers to the three sets of routine readings at colliery C_{11}. At this particular colliery both sets of routine readings by Observer A were in close agreement with the definitive classification but Observer B tended to read significantly higher. The proportions of consistent readings were respectively 97·2, 97·6 and 96·9% on Observer A's first and second readings and Observer B's single reading.

When the proportions of films on which the routine and definitive readings were consistent are compared with the percentage of men classed as category 0 on the corresponding set of definitive

TABLE 2

FIRST SURVEY AT COLLIERY C_{11}: COMPARISON OF ROUTINE AND DEFINITIVE READINGS

No. of Films

(a) Observer A's First Reading

Observer A \ Definitive	0	1	2	3	A	B, C, D	All
0	1,190	12					1,202
1	11	24	6		1		42
2		5	11	1			17
3				3			3
A					3		3
B, C, D						2	2
All	1,201	41	17	4	4	2	1,269

Percentage of consistent readings 97·2

(b) Observer A's Second Reading

Observer A \ Definitive	0	1	2	3	A	B, C, D	All
0	1,195	14					1,209
1	6	24	5		1		36
2		3	12	1			16
3				3			3
A					3		3
B, C, D						2	2
All	1,201	41	17	4	4	2	1,269

Percentage of consistent readings 97·6

(c) Observer B's Reading

Observer B \ Definitive	0	1	2	3	A	B, C, D	All
0	1,180	8					1,188
1	20	27	2				49
2		5	13				18
3			1	4			5
A	1	1	1		4		7
B, C, D						2	2
All	1,201	41	17	4	4	2	1,269

Percentage of consistent readings 96·9

readings it is found that the amount of agreement increases with the proportion of "normal" films. The general level of consistency is, however, considerably higher than that between the duplicate readings by the same observer. This confirms that the definitive readings are subject to appreciably less error than any single set of routine readings. There is on the whole very little difference between the general levels of performance of Observers A and B. In general, the consistency of the second survey readings tends to be higher than that of the first survey readings at the same colliery.

The variation in time of the standards applied on the corresponding routine and definitive readings is illustrated in Tables 3 and 4, which refer respectively to the readings at the collieries surveyed by

TABLE 3

COMPARISON OF ROUTINE AND DEFINITIVE READINGS AT COLLIERIES SURVEYED BY OBSERVER A

Observer	Colliery														
	C_1	C_2	C_6	C_7	C_9	C_{11}	C_{13}	C_{16}	C_{17}	C_{19}	C_{21}	C_{22}	C_1*	C_9*	C_2*
Observer A's first reading	0	0	+	−	−	0	−	−	+	+	+	+	0	+	+
Observer A's second reading	0	+	+	−	−	−	−	0	+	+	The second routine reading was discontinued at this point				
Observer B's reading	+	+	0	+	−	+	−	0	−	0	0	0	0	−	−
Date of survey	12/53	3/54	5/54	9/54	12/54	2/55	4/55	6/55	12/55	3/56	5/56	6/56	11/57	4/58	9/58

Notes + = Significantly higher than definitive reading.
0 = No significant difference between routine and definitive readings.
− = Significantly lower than definitive reading.
* Second survey.

TABLE 4

COMPARISON OF ROUTINE AND DEFINITIVE READINGS AT COLLIERIES SURVEYED BY OBSERVER B

Observer	Colliery														
	C_2	C_4	C_5	C_8	C_{10}	C_{12}	C_{14}	C_{15}	C_{18}	C_{20}	C_{23}	C_{24}	C_{25}	C_2*	C_{28}	C_4*
Observer B's first reading	0	+	0	+	0	0	+	−	+	+	0	−	−	−	+	0
Observer B's second reading	+	+	0	0	0	0	−	−	+	0	0	−	−	The second routine reading was discontinued at this point		
Observer A's reading	0	−	−	−	+	+	+	+	−	−	0	+	+	+	−	0
Date of survey	11/53	2/54	5/54	6/54	9/54	11/54	2/55	5/55	6/55	11/55	1/56	4/56	6/56	11/57	4/58	6/58

Notes—As for Table 3. * Second survey.

Observers A and B. These results are based on a series of two-way tables of the same form as Table 2, and the routine readings have been classed as either (i) not significantly different from the definitive readings, (ii) significantly higher than the definitive readings or (iii) significantly lower than the definitive readings. This comparatively simple index of comparison was adopted in the absence of any more convenient method of presentation, although a detailed mathematical analysis of the results (Fay and Ashford, 1960) does provide a quantitative measure of the differences in reading levels. When considering these results it should be borne in mind that on the first surveys the routine and definitive readings at a colliery may cover a period of as long as a year and that there may be an interval of several months between any two successive sets of readings.

The main point which emerges from Tables 3 and 4 is that the reading levels of both doctors show definite and systematic fluctuations in time, in comparison with the definitive readings. In general, it is found that when one observer is reading high the other is reading low, and vice versa, although this is not always the case. The definitive readings depend largely on the joint discussion sessions, which may take place many months after the routine readings, and they appear to represent the average of the current reading levels of the two observers.

The average reading levels of the two doctors on the first round of medical surveys are compared with the definitive readings in Tables 5 (Observer A) and 6 (Observer B). Reference to the results given in Table 5 (a) shows that at the collieries surveyed by Observer A his routine readings were, on average, in close agreement with the definitive readings, the only appreciable difference being on the boundary between categories 2 and 3, where he tended to read somewhat higher than the definitive level. At the collieries surveyed by Observer B on the other hand (Table 5 (b)) Observer A tended to read lower than the definitive readings on the boundary between categories 0 and 1, and higher on the boundaries between categories 1 and 2, and 2 and 3. When all collieries are considered (Table 5 (c)) a similar trend is apparent. Reference to Tables 6 (a), 6 (b), and 6(c) shows that Observer B's reading levels were higher than the definitive levels at the collieries surveyed by both himself and Observer A. When all collieries are considered Observer A's routine readings were consistent with the definitive readings on 92·1% of films and Observer B's routine readings

TABLE 5

COMPARISON OF OBSERVER A's ROUTINE READINGS WITH THE DEFINITIVE READINGS
FIRST MEDICAL SURVEYS

(a) COLLIERIES SURVEYED BY OBSERVER A

Observer A \ Definitive	0	1	2	3	A	B, C, D	All
0	25,578	630	31		7		26,246
1	603	1,675	225	1	27		2,531
2	14	248	725	42	33		1,062
3		5	90	236	21		352
A	3	28	59	12	264	8	374
B, C, D	3	2	2		37	150	194
All	26,201	2,588	1,132	291	389	158	30,759
					Percentage of consistent readings		93·1

(b) COLLIERIES SURVEYED BY OBSERVER B

Observer A \ Definitive	0	1	2	3	A	B, C, D	All
0	12,612	555	23	1	10	2	13,203
1	339	942	172	3	9		1,465
2	11	210	632	42	20		915
3			77	186	12		275
A	1	25	27	14	322	17	406
B, C, D		2	2	1	15	137	157
All	12,963	1,734	933	247	388	156	16,421
					Percentage of consistent readings		90·3

(c) ALL COLLIERIES

Observer A \ Definitive	0	1	2	3	A	B, C, D	All
0	38,190	1,185	54	1	17	2	39,449
1	942	2,617	397	4	36		3,996
2	25	458	1,357	84	53		1,977
3		5	167	422	33		627
A	4	53	86	26	586	25	780
B, C, D	3	4	4	1	52	287	351
All	39,164	4,322	2,065	538	777	314	47,180
					Percentage of consistent readings		92·1

were consistent with the definitive readings on 91·4% of films.

The Sequences of Routine Readings

The method of classification by joint discussion was applied to all films on which the routine readings did not agree. Thus, the consistency of the routine readings, which is a reflection of both the inter- and intra-observer variation, is of considerable interest from the point of view of the overall accuracy of the reading procedure (Fay and Ashford, 1960).

There is a marked tendency for the percentage of consistent routine readings to increase with increasing proportions of "normal" films, and the

TABLE 6

COMPARISON OF OBSERVER B's ROUTINE READINGS WITH THE DEFINITIVE READINGS FIRST MEDICAL SURVEYS

(a) COLLIERIES SURVEYED BY OBSERVER B

Observer B \ Definitive	0	1	2	3	A	B, C, D	All
0	23,995	749	34		24		24,802
1	973	2,201	301	2	37	2	3,516
2	17	368	1,295	88	45	3	1,816
3		2	129	376	16		523
A	8	21	34	9	594	31	697
B, C, D		3	1		40	271	315
All	24,993	3,344	1,794	475	756	307	31,669

Percentage of consistent readings 90·7

(b) COLLIERIES SURVEYED BY OBSERVER A

Observer B \ Definitive	0	1	2	3	A	B, C, D	All
0	13,538	331	16		6	2	13,893
1	372	881	91		14		1,358
2	15	170	443	31	20		679
3		4	54	127	5		190
A	4	8	15	2	159	9	197
B, C, D		1	1		6	71	79
All	13,929	1,395	620	160	210	82	16,396

Percentage of consistent readings 92·8

(c) ALL COLLIERIES

Observer B \ Definitive	0	1	2	3	A	B, C, D	All
0	37,533	1,080	50		30	2	38,695
1	1,345	3,082	392	2	51	2	4,874
2	32	538	1,738	119	65	3	2,495
3		6	183	503	21		713
A	12	28	49	11	753	40	894
B, C, D		4	2		46	342	394
All	38,922	4,739	2,414	635	966	389	48,065

Percentage of consistent readings 91·4

figures reported at the collieries where three such readings were made vary from about 60 to 95%. When the results obtained on the films belonging to the various definitive categories are considered separately there are wide variations in the consistency of the routine readings from category to category. For the films assigned to definitive category 0 the proportion of consistent routine readings increases very slightly with increasing proportions of normal films, with an average of about 92%. For films assigned to the other definitive categories, however, the proportion of consistent readings is independent of the distribution of abnormality and average figures of about 25%, 37%, 55% and 54% were respectively reported for categories 1, 2, 3, and P.M.F.

Consistency of the Definitive Readings

The reading procedures on the first round of medical surveys were such that it is not possible to obtain any estimate of the consistency of the definitive readings. During the second surveys, however, a random sample of the first survey films is classified again and a comparison of the corresponding definitive readings provides a measure of their repeatability over a long period of time. At collieries C_1-C_3 the whole of the random sample consisted of films on which the routine readings on the first survey were inconsistent, but at collieries C_4 and C_5 a quarter of the sample was selected from films on which the original routine readings were consistent.

Details of the definitive readings recorded at the various collieries on the films on which there was disagreement on the original routine readings are given in Table 7. The main point of interest is the fact that at four of the five collieries (C_2-C_5) there

TABLE 7

COMPARISON OF DEFINITIVE READINGS ON SAMPLE OF FIRST SURVEY FILMS ON WHICH THE ORIGINAL ROUTINE READINGS WERE INCONSISTENT

(a) COLLIERY C_1

	First Survey							
Second Survey	Category	0	1	2	3	A	B, C, D	All
	0	40	14	2				56
	1	4	20			1		25
	2			4				4
	3							
	A					1		1
	B, C, D						1	1
	All	44	34	6		2	1	87
							Percentage of consistent readings	75·9

(b) COLLIERY C_2

	First Survey							
Second Survey	Category	0	1	2	3	A	B, C, D	All
	0	12	5	1				18
	1	7	13	6		2		28
	2		9	9	1			19
	3			2	2			4
	A			1		4	1	6
	B, C, D						1	1
	All	19	27	19	3	6	2	76
							Percentage of consistent readings	53·9

(c) COLLIERY C_3

	First Survey							
Second Survey	Category	0	1	2	3	A	B, C, D	All
	0	62	23	1				86
	1	15	31	8				54
	2		3	4	2			9
	3				1			1
	A		1	2		3		6
	B, C, D					1		1
	All	77	58	15	3	4		157
							Percentage of consistent readings	64·3

TABLE 7—*continued*

(d) COLLIERY C_4

Second Survey \ First Survey	0	1	2	3	A	B, C, D	All
0	47	22					69
1	19	35	11		1		66
2		7	9	2	1		19
3			1	4	1		6
A			1		7	3	11
B, C, D					2	2	4
All	66	64	22	6	12	5	175

Percentage of consistent readings 59·4

(e) COLLIERY C_5

Second Survey \ First Survey	0	1	2	3	A	B, C, D	All
0	41	8	1				50
1	10	38	5		1		54
2		3	15	1	2		21
3			2		1		3
A		2	4		7	2	15
B, C, D		1	1			3	5
All	51	52	28	1	11	5	148

Percentage of consistent readings 70·3

was no evidence of any significant change in reading levels. At one colliery (C_1) the second survey readings were significantly lower than the first. Further investigation of this anomalous result showed that it was due to a temporary variation in the reading levels of one of the doctors on his second survey readings of the check films, and arrangements were made to reclassify the films concerned. The corresponding first and second survey definitive readings on the sample of first survey films on which the original routine readings were consistent are compared in Table 8. The two sets of readings were consistent on all except one of the 83 films concerned and this single difference was of one category only.

The proportions of consistent definitive readings on the films on which there was disagreement between the original routine readings vary from 53·9% to 75·9% with an average of about 65%. When considering these results it should be borne in mind that the films concerned are deliberately selected to cover the most difficult cases. They represent, on average, only about one-fifth of the total number and almost 100% of the definitive readings on the remaining four-fifths are consistent.

Discussion

The main feature of these results is the fact that the reading levels of two very experienced doctors exhibit marked fluctuations over a long period of time, as revealed both by the comparison of the duplicate readings by the same observer and of the corresponding readings by different observers. In spite of these variations the standards applied on the definitive readings appear to remain remarkably constant, even over a period of as long as five years. This indicates that the method of joint discussion, which applies to the majority of films lying on the borderline between two categories (Fay and Ashford, 1960) does lead to a reasonably stable reading standard and confirms that the film reading procedures described provide a satisfactory way of measuring the prevalence of radiological pneumoconiosis.

The presence of systematic variations in individual reading levels suggests that it would probably be desirable, in a programme of film reading such as that being carried out by the Pneumoconiosis Field Research, to increase the number of film readers. In this way any "averaging" procedure used to obtain the definitive readings should provide more

TABLE 8

COMPARISON OF DEFINITIVE READINGS ON SAMPLE OF FIRST SURVEY FILMS ON WHICH THE ORIGINAL READINGS WERE CONSISTENT

(a) COLLIERY C_4

Second Survey \ First Survey	0	1	2	3	A	B, C, D	All
0	42						42
1		1					1
2			1				1
3				1			1
A							
B, C, D							
All	42	1	1	1			45

Percentage of consistent readings 100·0

(b) COLLIERY C_5

Second Survey \ First Survey	0	1	2	3	A	B, C, D	All
0	34	1					35
1		2					2
2			1				1
3							
A							
B, C, D							
All	34	3	1				38

Percentage of consistent readings 97·4

stable results than can be obtained with two readers. Even amongst a large group of film readers, the use of frequent joint reading sessions to classify the films on which the routine readings do not agree should ensure that each reader becomes aware of any possible deviations of his own standards from those of the team as a whole. The various sets of routine and definitive readings carried out on the first medical surveys at each colliery extended over a long period of time and it was not therefore possible to provide the doctors with up-to-date information about their current performance. On the second surveys, however, the readings at each colliery are normally completed within a period of at most three months, and are analysed and discussed with the doctors before the next survey is undertaken. This close monitoring of standards has already led to an increase in the consistency of the routine readings and has had the effect of reducing periodic fluctuations in the doctors' average standards of classification. Our present experience suggests that some system of this kind must be followed if the best use is to be made of the effort applied by the film readers.

Another major feature of the analysis is the tendency for the magnitude of the reading errors on a batch of films to increase with increasing amounts of abnormality in the batch. When the various categories of pneumoconiosis (other than category 0) are considered separately, however, this trend is not apparent, although there are marked differences in the average error from category to category.

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THE RELATIONSHIP OF BYSSINOSIS TO THE BACTERIA AND FUNGI IN THE AIR OF TEXTILE MILLS

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The principal causative agent of byssinosis lies in the dust of cotton mills. This dust contains bacteria and fungi. An attempt has been made to determine whether any association could be established between the numbers of viable bacteria and fungi in the air of two cotton and two jute mills, and the prevalence of byssinosis. No association was found except between the numbers of live organisms of *B. pumilus* and *B. subtilis*, and the occurrence of byssinosis. This association does not establish a causal relationship, but it is suggested that an attempt should be made to produce typical symptoms in byssinotic subjects by means of organisms of the genus *Bacillus*. A subsequent paper presents the results of some observations of this kind.

It is generally accepted that the causative agent of byssinosis lies in the dust produced during the preparation of cotton for spinning. This dust contains fragments of the cotton plant, bacteria, fungi, and mineral salts, and silica derived from the soil. Bacteria and fungi have been shown to occur in high concentrations in the air of cardrooms (Drummond and Hamlin, 1952) and must be suspected when considering the possible aetiology of byssinosis. Thiry (1941), for example, has suggested that moulds and bacteria are the cause of the disease in flax workers. Since there is no evidence that byssinosis is an infection, both dead and live organisms should be considered. Attempts to estimate the total concentration of organisms by microscopic examination of the dust from the air of textile mills proved too unreliable to be of value owing to admixture with other materials. With direct studies upon byssinotic subjects as the ultimate aim, the investigation, described in this paper, was instituted to see whether there was a relationship between the concentration of live organisms in the air and the incidence of byssinosis.

Method

Mills Investigated.—Two cotton mills (A and B), in which the incidence of byssinosis in the cardrooms had been determined, were selected for study. A was a cotton mill spinning coarse counts of cotton; B a cotton mill spinning fine counts of Egyptian cotton. A was more dusty than B. The total dust concentrations measured gravimetrically by the Hexhlet apparatus have already been published (Roach and Schilling, 1960).

Two jute mills (C and D) were also selected. Dust concentrations, measured with a thermal precipitator, showed that mill C had a mean dust count of 325 particles per ml. The corresponding figure for mill D was 182.

The part of the mill selected for study was the cardroom where the fibres are opened and combed preparatory to spinning. This is the dustiest process in the mill and Schilling (1956) has shown that it has the highest incidence of byssinosis.

Sampling.—The concentration of live micro-organisms in the air was determined by means of a slit sampler and by a Hexhlet apparatus (Wright, 1954).

With the very high concentrations found, the ordinary method of using a slit sampler, by exposing nutrient agar plates, although reducing the sampling time to a few seconds was found to produce overcrowding of the colonies and the following modification of the method was therefore devised.

The petri dishes were prepared with a thin layer of 1% agar in tap water. Each dish was exposed in the sampler for 30 minutes when the agar was removed and transferred to a jar packed in ice. Plates were exposed successively for a total sampling time of three to four hours. In this way a sample was obtained representative of the concentration during the day.

The total mixed specimen, at the completion of sampling was homogenized in approximately 100 ml.

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saline (measured after mixing, in order to include saline needed to wash out the container) in an Atomix* at half speed (6,000 r.p.m.) for three minutes and then inoculated on to the surface of appropriate solid media. If necessary the agar mixture was diluted. The extent of this dilution and the volume to be inoculated were determined by preliminary trial with other samples from the same source.

The Hexhlet apparatus sucked air through a filter-paper disc and was run for the whole of the working day. The filter paper was macerated in the Atomix and inoculated on to plates in a similar manner to the homogenized agar.

Media.—The medium used for culturing bacteria was a meat extract peptone-agar, which, after pouring, was dried for two hours in a 37°C. incubator to prevent spreading of colonies. The inoculum was spread evenly over the surface and plates were incubated for 24 hours at 37°C. and for 24 hours at 22°C., when the colonies were counted. Twelve plates were used for each determination and the number of colonies per plate was usually between 50 and 200. It was found advisable to restrict the volume of inoculum to a maximum of 0·25 ml., as larger volumes tended to induce spreading of some colonies.

The medium used for culturing fungi consisted of a dextrose—peptone-agar base with 1 : 30,000 Rose Bengal and 30μg. ml. streptomycin (Martin, 1950). It was only necessary to dry the plates sufficiently to remove excess moisture. These plates were incubated at 22°C. for three days. As with the bacteria, 12 plates were used for each determination and they contained a similar number of colonies. A larger volume of inoculum could be used for fungi than for bacteria but it was found to be inadvisable to exceed 1 ml., as larger volumes were not always completely absorbed.

Evaluation of Method.—In the course of the investigation a comparison was made between the results obtained with the slit sampler used in the manner described (homogenizing method) and the standard method using nutrient agar plates. A site was chosen where the concentration of air-borne organisms was sufficiently low to produce well-separated colonies with the standard method and a sampling time of five minutes.

The dispersion of bacterial aggregates by the homogenizing method increased the count by a factor ranging from 3·9 to 7·4 with a mean of 5·3 (Table 1).

A comparison was also made between the results of counting bacteria by the slit sampler homogenizing technique and by using the Hexhlet apparatus.

Five samples taken in the cardroom of mill B with the Hexhlet gave a mean of 2,800 organisms per cu. ft. while seven samples with the slit sampler gave a mean of 3,300. The lower count given by the Hexhlet may well be due to the desiccating effect of the air flow through the apparatus, which was 100 l. min. for a sampling time of nine hours, or to a difference in the efficiency of dispersing clumps of bacteria depending on whether they were on an agar gel or on filter paper.

* Measuring and Scientific Equipment Co., London.

TABLE 1

VIABLE BACTERIA IN A COMBING ROOM ESTIMATED BY A SLIT SAMPLER

(Organisms per cu. ft.)

Homogenizing Method	Standard Method	Ratio H/S
448	61	7·4
748	102	7·3
358	82	4·4
331	84	3·9
627	123	5·1
411	89	4·6
806	186	4·3

Results

The concentration of viable micro-organisms in the cardrooms of all four mills was very high (Table 2).

The highest mean figures (bacteria plus fungi) were in the jute mill C and the mill spinning coarse cotton A; the lowest were in the cotton mill spinning fine counts B with the jute mill D in an intermediate position. There was considerable variation from day to day in any one site.

In all cases the bacteria outnumbered the fungi, the commonest bacteria being those of the genus *Bacillus*. Within this genus the species differed in the two types of mill, *B. subtilis* and *B. pumilus* being the only species found in the cotton mills, while *B. megaterium* predominated in the jute mills (Table 3).

The fungi were mainly of the genera *Aspergillus* and *Penicillium*, the highest numbers being in the jute mills. Actinomycetes were found in particularly high concentrations in jute mill C.

Discussion and Conclusions

In the cotton mill A, 72 of the 135 cardroom workers had symptoms of byssinosis whilst in B only five of the 32 at risk were so affected. Although previous investigations (Schilling, 1956), had failed to reveal byssinosis in jute workers it appeared possible that three of the 16 workers at risk in the jute mill C and one of 14 in D might have mild manifestations of the disease. Thus it was presumed that the incidence of byssinosis throughout the four mills investigated ranged from a high prevalence in A down to virtual absence in D.

No association was established between the total concentration of live micro-organisms in the atmosphere and the incidence of byssinosis. In cotton mill A and jute mill C the concentration was similar and approximately 10 times greater than that in B. Nor did there appear to be any relation between either the total number of bacteria or the total number of fungi present in the atmosphere and the prevalence of byssinosis. The occurrence of

TABLE 2

Mill	Bacteria			Fungi		
	No. of Readings	No. per cu. ft.		No. of Readings	No. per cu. ft.	
		Range	Mean		Range	Mean
A	12	20,200 70,300	36,400	2	1,900 2,650	2,300
B	7	2,500 3,900	3,300	2	485 542	510
C	7	13,000 61,000	32,400	3	4,700 13,000	8,817
D	3	2,300 3,600	3,090	2	730 3,300	2,000

TABLE 3

VIABLE ORGANISMS PER CUBIC FOOT OF AIR

Mill	Total Organisms	Total Bacteria	Total *Bacillus* Species	*B. pumilus* + *B. subtilis*	*B. Megaterium*	Micrococcus	Actinomyces	Total Fungi	*Aspergilli*	*Penicillium*
A	38,700	36,400	27,700	27,700	—	6,550	2,190	2,300	700	400
B	3,800	3,300	3,000	3,000	—	160	0	510	260	240
C	41,217	32,400	12,000	1,900	10,000	4,540	15,850	8,817	2,210	5,640
D	5,090	3,090	1,518	188	1,330	806	494	2,000	480	1,320

individual genera was also haphazard with the exception of the genus *Bacillus*. There appeared to be definite association between the incidence of byssinosis and the number of live organisms of *B. pumilus* and *B. subtilis*. This does not necessarily establish a causal relationship between the two. Furthermore, since byssinosis is not an infection, not only should dead as well as live micro-organisms be considered but also the by-products of growth, and whether they are in the spore or vegetative stage. Thus the amount of bacterial or fungal substance in dust which originates from a particular species and which might be concerned in causing byssinosis is not necessarily indicated by the viable count of that organism.

In view of the difficulty in interpreting the results it would seem that there is little to be gained by further examination of cardroom dust for micro-organisms. The next and essential step is to attempt to produce typical symptoms in byssinotic subjects under controlled conditions. It is in this way that the causal relationship of a particular material to byssinosis may best be investigated. The present investigation has suggested that the genus *Bacillus* should be tested in such direct investigation. A further paper presents the results of some observations of this kind (Tuffnell, 1960).

I wish to thank Professor H. B. Maitland and Dr. R. S. F. Schilling for suggesting this investigation and for constant assistance; also Professor W. J. Tulloch for hospitality in Dundee, Dr. D. G. Drummond for the loan of a slit sampler and Dr. R. E. O. Williams and Surgeon Commander H. M. Darlow for the loan of other instruments. Mr. S. A. Roach provided the Hexhlet samples.

I am much indebted to Professor R. E. Lane and Miss I. Dingwall-Fordyce. Finally, without the cooperation of the mill managements this investigation would not have been possible.

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EXPERIMENTAL BYSSINOSIS

BY

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The symptoms of byssinosis were produced experimentally in one of three cotton-mill workers with pronounced byssinosis, by a dust prepared from the leaves of cotton plants. Dusts of calcium carbonate, bacteria, and fungi did not reproduce the symptoms. Two mild cases of byssinosis and two cases of chronic bronchitis did not react specifically to any of these dusts.

It is generally accepted that the cause of byssinosis lies in the dust in the air of textile mills. Environmental surveys have not provided any evidence to suggest which of the substances composing the dust may be responsible for the disease†. This paper presents the results of the inhalation of cotton-mill dust and some of its constituents upon five men with byssinosis and two with bronchitis.

Cotton dust consists of fragments of cotton fibre and cotton plant, bacteria, fungi, silica, and mineral salts. Of these, bacteria, fungi, and cotton plant leaf were selected for study.

Types of Dust

The following types of dust were used:

(1) *Calcium carbonate.* This was selected for use as a control since it has been shown that prolonged inhalation of pure calcium carbonate has no ill effects (Davis and Nagelschmidt, 1956). It was also used for diluting the powders of bacteria and fungi.

(2) *Bacillus pumilus.* This organism is one of the most common in the air of cotton mills and there is an association between its concentration and the incidence of byssinosis (Tuffnell, 1960). A strain, isolated from a cotton mill, was grown on nutrient agar, suspended in isotonic saline, and lyophilized. The granular powder so produced was finely ground in a mortar and diluted with calcium carbonate to give sufficient bulk to be handled easily in the dust dispersing machine.

(3) *Aspergillus niger.* This organism was the most common single species of fungus found in the air of cotton mills. A strain recently isolated from cotton dust was grown on peptone-glucose agar until well developed (two weeks), allowed to dry in a 37°C. incubator, and then scraped off the plates. The resulting powder was diluted suitably with calcium carbonate.

(4) *Cotton plant leaf.* A quantity of cotton bolls was obtained from Nigeria. Fragments of leaf and bract were picked off the bolls and pounded with glass beads in a flask shaker until reduced to a fine dust which was then sieved through a 90 mesh sieve.

(5) *Cotton mill dust.* The material in the card-room air extraction plant filters of a mill spinning fine counts of Egyptian cotton was sieved through a 90 mesh sieve.

Cases

Seven males volunteered for the experiments. Two had chronic bronchitis and had never worked in a textile mill. The other five were cotton workers of whom three had been examined by a Pneumoconiosis Medical Panel and were receiving pensions for byssinosis; the remaining two had been diagnosed as cases of mild byssinosis during a field investigation.

Method

Dust Dispersion.—The dusts were dispersed by means of an apparatus consisting of a gauze-covered cylinder driven by an electric clock motor rotating beneath a small reservoir containing powder. A stream of air from a vacuum cleaner flowed across the lower surface of the cylinder into the atmosphere (see Fig.). The dust was discharged at a height of three feet above an electric fan at floor level, into an experimental room of 1,000 cu. ft. capacity.

Estimation of Dust Concentration.—The number of particles between 0·5 and 7·5 μ/ml. of air was estimated with a thermal precipitator. A Hexhlet apparatus was

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† Since this investigation was completed, Roach and Schilling (1960) have described a combined clinical and environmental study which attempts to provide some evidence as to the causal agent of byssinosis.

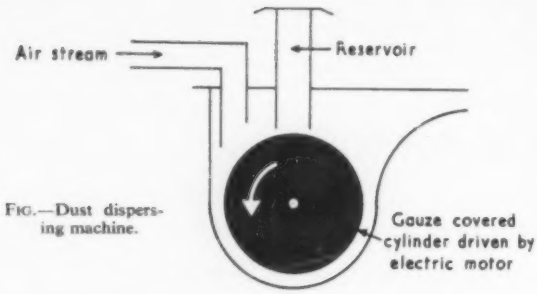

FIG.—Dust dispersing machine.

used to obtain samples which were analysed for nitrogen content. This was fitted with an elutriator which trapped particles of more than 7·1 μ diameter and allowed most particles of less than 5μ to pass through (Wright, 1954).

Bacteria.—The concentration of viable bacteria was determined by a slit-sampler using the homogenizing technique described in a previous paper (Tuffnell, 1960).

Experimental Method.—Preliminary trials determined the amount of each dust required to produce concentrations similar to those found in the cotton mills. Measured quantities of the dusts were fed into the dispersing machine at hourly intervals, each sample taking about 10 minutes to disperse.

Samples were taken with the thermal precipitator for a period of 10 minutes in each hour, from 30-40 minutes after dispersal began. Samples with the slit sampler were taken for a period of half an hour commencing 15 minutes after dispersal began. Details of the mean dust concentrations, to which each subject was exposed, are shown in the Table below.

Case No.	Particles per ml. (Thermal Precipitator)			Viable Organisms per cubic foot (slit sampler)	
	$CaCO_3$	Leaf	Mill Dust	*B. pumilus*	*A. niger*
1	434	269	179	3,050	350
2 and 3	377	451	249	1,510	2,360
4 and 5	689	299	—	12,700*	7,300
				7,400	
6 and 7	943	517	413	2,390	3,750
		507*			

* Two separate occasions.

As was to be expected there was no detectable nitrogen in the samples containing organisms. There was, however, an appreciable amount in the leaf and mill dust.

The experimental subjects were exposed to each dust for four hours, two hours in the morning and two in the afternoon with a one-hour interval between. Before and after each two-hour session the Maximum Breathing Capacity (M.B.C.) was estimated for each subject with a modified Gaensler apparatus (Gaensler, 1951). They did not exercise during the experiments.

Case Results

Case 1.—A retired blow-room worker, 61 years of age, was in receipt of 30% disability pension. Exposure to calcium carbonate produced no subjective or objective reaction. The dust containing *Bacillus pumilus* and that containing *Aspergillus niger* produced no subjective effect, but with each dust there was a slight reduction in the M.B.C. Leaf dust produced a pronounced reduction in the M.B.C. and a subjective reaction that was similar to, but rather worse than, that he experienced while working on a Monday in the cotton mill. A similar effect was produced by inhaling the preparation of mill dust. Details are set out below:

Dust	M.B.C. (l./min.)			
	9.30 a.m.	12 noon	1.30 p.m.	4 p.m.
Calcium carbonate	54	59	—	55
B. pumilus	67	60	61	53
A. niger	72	62	69	55
Leaf	71	51	47	39
Mill dust	65	48	45	32

Cases 2 and 3.—Both these men were cardroom workers; Case 2 was 36 years of age and Case 3, 35 years. They had been diagnosed as mild cases of byssinosis during a field investigation. Neither developed any subjective or objective reaction to any of the dusts used in the experiment. Subsequently they were seen in the mill in which they worked, a dusty one, at the end of a normal working Monday. Their M.B.C.s were found to be similar to the values recorded at the same time of day during the experimental period. Neither man was breathless either objectively or subjectively, their only complaint being dryness of the throat. It would seem either that these two workers were not suffering from byssinosis or that the disease was in a very early stage. Details for Case 2 are set out below:

Dust	M.B.C. (l./min.)			
	9.30 a.m.	12 noon	1.30 p.m.	4 p.m.
Calcium carbonate	141	135	137	135
B. pumilus	140	135	138	138
A. niger	135	139	139	132
Leaf	127	129	125	131
Mill dust	139	136	130	130

Details for Case 3 are set out below:

Dust	M.B.C. (l./min.)			
	9.30 a.m.	12 noon	1.30 p.m.	4 p.m.
Calcium carbonate	144	138	138	144
B. pumilus	153	147	147	145
A. niger	148	147	147	148
Leaf	142	146	147	143
Mill dust	150	150	152	148

Case 4.—A cardroom worker, 60 years of age, was receiving a 40% disability pension for byssinosis. The disease was of moderate degree, less severe than Case 1. After exposure to dusts of calcium carbonate, *B. pumilus* and *A. niger* he complained of dryness of the throat, slight cough, and increased sputum, but there was no significant fall in the M.B.C. Exposure to leaf dust produced a fall in the M.B.C. which, however, was not accompanied by any subjective effect.

Dust	M.B.C. (l./min.)			
	9.30 a.m.	12 noon	1.30 p.m.	4 p.m.
Calcium carbonate	88	87	93	86
B. pumilus	92	85	91	87
B. pumilus	85	80	86	80
A. niger	88	87	85	85
Leaf	88	79	86	75

Case 5.—This man, 50 years of age, suffered from chronic bronchitis; he had never worked in a textile mill. All the dusts produced an increase in cough and sputum and some dryness of the throat. The M.B.C. showed a change of similar degree with each dust.

Dust	M.B.C. (l./min.)			
	9.30 a.m.	12 noon	1.30 p.m.	4 p.m.
Calcium carbonate	65	64	62	60
B. pumilus	65	56	55	52
B. pumilus	59	53	52	51
A. niger	60	—	56	52
Leaf	59	57	56	55

Case 6.—A retired cardroom worker, 67 years of age, received a 50% disability pension for byssinosis. He had no symptoms after exposure to any of the dusts except some feeling of dryness of the throat. The M.B.C. was reduced after exposure to the leaf dust (on two occasions) and after exposure to the mill dust.

Dust	M.B.C. (l./min.)			
	9.30 a.m.	12 noon	1.30 p.m.	4 p.m.
Calcium carbonate	67	63	70	75
B. pumilus	73	72	71	71
A. niger	73	72	75	71
Leaf	75	69	71	64
Leaf	75	71	72	67
Mill dust	72	69	68	67

Case 7.—This man, 49 years of age, suffered from chronic bronchitis and had never worked in a textile mill. All the dusts produced an increase in cough and sputum and similar, but not marked, changes in the M.B.C.

Dust	M.B.C. (l./min.)			
	9.30 a.m.	12 noon	1.30 p.m.	4 p.m.
Calcium carbonate	79	75	73	72
B. pumilus	78	83	79	76
A. niger	73	76	83	75
Leaf	71	76	75	68
Mill dust	71	71	74	67

Discussion

From the results obtained with Case 1 it seemed that it might be possible to reproduce, under experimental conditions, a type of reaction which resembled byssinosis. This man's reaction to leaf and mill dust was pronounced and exactly resembled his symptoms when working in the blowing room. It appeared to be specific in view of the absence of reaction to the other dusts. Unfortunately such clear cut results did not follow with any of the other cases of byssinosis.

Cases 2 and 3, in whom mild byssinosis had previously been diagnosed, had no detectable reaction either symptomatic or in the M.B.C. The absence of any significant symptoms or abnormal M.B.C.'s in these two cases after an ordinary working Monday makes it reasonable to presume that they were very mild cases of byssinosis and only developed symptoms under extreme conditions.

Cases 4 and 6 both had moderately severe byssinosis and were in receipt of disability pensions. The reaction to leaf dust by Case 4 and to leaf and mill dust by Case 6 differed from their reaction to the other dusts only in respect of the reduction in the M.B.C. Neither experienced any symptoms which resembled byssinosis.

The two subjects with chronic bronchitis reacted, to a slight and similar extent, to each of the dusts, with increased cough and sputum and a slight fall in the M.B.C. There was no evidence of any specific reaction in either case.

There are several possible explanations for the inability to reproduce the symptoms of byssinosis experimentally in two of the three subjects with pronounced byssinosis. Though the concentration of dust was similar to that found in cotton mill cardrooms, working conditions were not simulated, for the subjects were exposed to the dust for only four hours and they were not exercising. Increased pulmonary ventilation for a longer period may be necessary to produce symptoms in some cases of byssinosis. Also, the dusts were prepared at one time so that they were several months old when used for the later subjects. It is possible that a freshly fractured leaf fragment may be active and that oxidation reduces the activity.

The occurrence of byssinosis in textile mills other than cotton, and also in the waste cotton industry, suggests either that byssinosis may be a pulmonary reaction to a variety of substances, or that there is a common substance causing the disease.

I am indebted to the volunteer subjects and to the cotton mill managements that allowed their workers time off to undergo these experiments; also to Professor R. E. Lane for his constant encouragement, to Professor H. B. Maitland, Miss I. Dingwall-Fordyce, Mr. S. Roach, and Dr. R. S. F. Schilling, for their frequent advice and assistance.

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SICKNESS ABSENCE AMONG FORESTRY WORKERS IN THE NORTH OF SCOTLAND, 1958

BY

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The sickness absence records of 1,115 forest workers in the highlands of Scotland during 1958 were examined. Only absences of four days or more were considered. Two hundred and seventy of the workers were established and were therefore entitled to retirement pensions. There was a high proportion of older men among the established workers; but the sickness record of these men was generally better than that of the unestablished workers except in respect of cardiovascular disease, rheumatism, and arthritis.

Among forest workers as a whole, accidents off duty accounted for more sickness absence than accidents on duty, a reversal of the finding in the male working population at large. The second most important cause of sickness absence was back troubles of all kinds. Among the male working population at large the second most important cause of absence was bronchitis, a disease which among forest workers comes 13th on the list.

A comparison was made between the sickness absence record of the highland forest workers and a group of telephone construction gang hands performing broadly comparable work (as regards health hazards) in the same area but whose members were drawn from more urban homes. In general fewer forest workers than telephone gang hands went sick in 1958 for all common ailments except cardiovascular disease, a finding perhaps related to the greater average age of forest workers. When this difference in age was allowed for it was found that the greatest difference between the two groups of sickness records was in bronchitis, cardiovascular disease, and peptic ulcer and gastritis, in that order, and was to the advantage of the forest workers. Next came the upper respiratory tract infections. The least difference was in accidents, septic conditions, and rheumatism and arthritis.

The forestry workers whose absence from work because of sickness is described in this paper, are those employed by the Forestry Commission's Scottish (North) Conservancy. They live and work in the most northerly part of the mainland and in the islands of Skye and Raasay (Fig. 1). The special interest that attaches to the health and physique of this group of men is that they are almost without exception permanent country dwellers; and it has been possible to throw into relief this account of a group of country people's sickness during the year by contrasting it with the sickness experienced by a similar sized group of men, engaged on an occupation resembling forestry in many of its features, but drawn from a more urban home environment.

The records examined relate to the calendar year 1958. The mid-year population is unobtainable, as the Forestry Commission's annual counting day is September 30. However, 1,115, the figure for September 30, 1958, is not exceptional as compared with previous years (between 1955 and 1958 it varied between 1,098 and 1,146), and provides an adequate measure of the average labour force employed in the Commission's forests in this part of the country throughout the year. The Commission's forests provide a permanent source of work for those who seek it, but many men only require casual or short term employment which is often available at busy seasons. For the regular worker there is a scheme under which he may, subject to length of service and satisfactory health record (examination by a doctor is not necessary) become a permanent, established employee entitled to superannuation benefits. At September 30, 1958 the total labour force of 1,115 was made up of 845 unestablished and 270 established workers.

FIG. 1.—Map of Scotland showing areas worked by highland forest workers and telephone construction gangs; - - - - - - - southern boundary of North Scotland Conservancy of the Forestry Commission; ..... southern boundary of the area in which Aberdeen and West of Scotland telephone external construction gangs work.

Age Structure of the Labour Force

The dates of birth of a random sample, amounting to about 20% (227) of all the men who had been employed by the Commission in the area during 1958, were noted and their ages worked out to the date September 30, 1958. Sixty-seven of the sample were established workers and 160 were unestablished. From the actual age structure of the sample an estimate was made of the age structure of the labour force at the counting date when the force amounted to 1,115 men. The results are given in Fig. 2 and Table 1.

Two points call for comment. One is the concentration of older men among the established workers. This phenomenon is a constant and well-recognized feature in the Commission's labour force in the North of Scotland. The other point is less expected. It is the surprisingly small representation of men aged 35 to 39 both among established and non-established groups. This finding may very well be a local manifestation of a countrywide phenomenon for agricultural and kindred occupations. Table 2 sets out some more or less comparable figures for the age structure of men occupied in agriculture, horticulture, and forestry as recorded in the 1951 Census for Scotland (General Registry Office, Edinburgh, 1956) and the highland forest workers described in this paper. The percentage age structure for highland forest workers found in 1958 has been converted into a hypothetical age structure for 1953 by moving the figures one

FIG. 2.—Estimated age structure of random sample of population at risk.

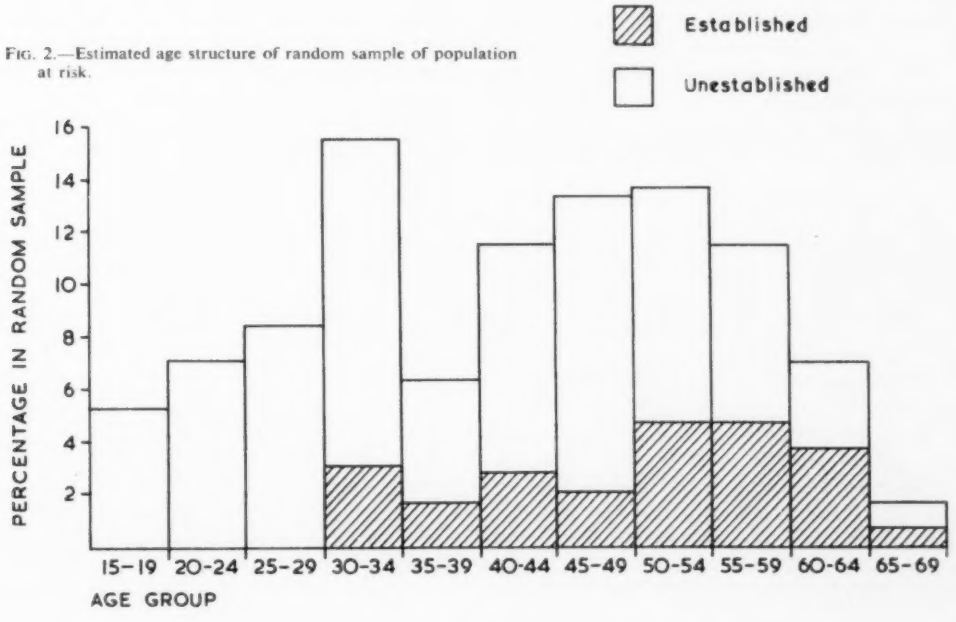

TABLE 1

ESTIMATED AGE STRUCTURE OF POPULATION AT RISK

Age Group (years)	Established in Labour Force (estimated)	Unestablished in Labour Force (estimated)	Age Structure of Labour Force (estimated)
15-19	0	58	58
20-24	0	85	85
25-29	0	101	101
30-34	36	137	173
35-39	16	53	69
40-44	32	90	122
45-49	24	126	150
50-54	56	90	146
55-59	56	63	119
60-64	46	37	83
65-69	4	5	9
Total	270	845	1,115

TABLE 2

AGE STRUCTURE OF NORTH SCOTTISH FOREST LABOUR FORCE, AND THAT OF MEN FOLLOWING AGRICULTURAL OCCUPATIONS IN SCOTLAND AT THE TIME OF THE 1951 CENSUS

Age Group	% N. Scottish Foresters (1958)	% N. Scottish Foresters (estimated 1953)	% Agricultural, Horticultural and Foresters (1951)
15-19	4·8	7·0	10·4
20-24	7·0	8·4	9·9
25-29	8·4	15·4	10·4
30-34	15·4	6·2	8·7
35-39	6·2	11·0	10·2
40-44	11·0	13·2	10·2
45-49	13·2	13·7	9·2
50-54	13·7	11·4	9·2
55-59	11·4	7·0	7·1
60-64	7·0	0·9	6·2
65-69	0·9	—	4·1

column to the left. In order to line these up with the census figures, the group in the latter for age 35-44 have been split in half, and so also for age 45-54. For the rest of the working life five-year groups are given in the Census Report. The curiously small representation of the 34-39 group is noticeable both in the Census figures and in those derived from the count of highland forest workers.

Sickness and Accident Absence

In this review no account has been taken of uncertificated or doubtfully certificated absences of one, two, or three days only; but in a few cases where absences of one, two, or three days were found with medical certificates bearing doctors' signatures, these have been counted. For various reasons these short absences are different in kind as well as in length from absences of four days or more. They are generally accompanied by a less precise medical diagnosis, if indeed they are accompanied by a medical certificate at all, and in practice it is sometimes difficult to distinguish them from absences attributable to some cause other than sickness. As this review concentrates on the kinds of sickness absence which accompany different diagnoses, no useful purpose is served by taking into account absences whose diagnostic attribution is questionable.

The diagnoses have been coded according to the 3-figure International Statistical Classification and then grouped under 32 convenient headings, whose brief title indicates the diagnoses which for the most part make up each group (Appendix I). The last of these headings, "Back troubles of all sorts" refers to a syndrome of particular importance among this group of workers. The spells of sickness absence due to back troubles appear also higher up in the Table in their appropriate place according to the diagnosis appearing on the medical certificate. The detailed breakdown of the syndrome appears in Table 3.

Some of these diseases or groups of diseases are more important in their industrial aspect than

TABLE 3

BACK TROUBLES OF ALL SORTS IN FOREST WORKERS OF NORTH SCOTTISH CONSERVANCY, 1958

Diagnosis	International Statistical Classification No.	1 No. of Workers Affected	2 No. of Spells	Total Man Days of Absence	3 Average Length of Spell (days)
Strained back	N847	14	14	227	16·2
Inter-vertebral disc region	N839	4	4	227	56·7
	735				
Back injury	N996	4	4	106	26·5
Lumbago	726	15	15	479	31·9
Sciatica	363	6	6	240	40
Backache	787	3	3	43	14·3
Sacroiliac strain	N846	4	4	97	24·2
Other	723	1	1	45	45
Total	—	48	51	1,464	28·7

1 Three workers had second attacks of back trouble with a different diagnosis.
2 Nine spells requiring reference to Treasury Medical Adviser.
3 Median spell 16 days.

others. Appendix I gives certain facts about each. Column 1 gives the number of workers absent in the year, and the rate per 100 workers; column 2 the number of spells of absence in the year, and the rate per 100 workers; column 3 the number of man-days of absence, and the rate per 100 workers; column 4 the average length of spell; and column 5 the length of the median spell. After a forest worker has been absent for six weeks his case papers are referred to the Treasury Medical Adviser for an opinion on prognosis. Column 6 lists the number of cases so referred for each group of diagnoses. On average one out of every five spells of absence here recorded (121 out of 621) were referred in this way.

Column 3 (man-days of absence) records the feature about the absences which is, perhaps, of greatest economic importance to the industry, and Column 7 lists the figures in Column 3 in order of magnitude. This method of assessing the prevalence or importance of conditions in the various diagnostic groups provides a convenient measure for comparison between one industry and another. In Appendix I it is remarkable that bronchitis is 13th out of 32 listed causes as an overall source of sickness absence. It is hardly less notable that in this industry "accidents occurring off duty" come first and "back troubles" of all sorts second in man-days of absence per 100 employed.

Back Troubles.—Back troubles are a serious hazard of working life in many kinds of employment, but observations about them are still not collected in a form in which their natural history can be studied, or comparisons made of their rates of occurrence in different industries. In the International Statistical Classification they are dispersed under eight different codings, and in the groupings used by the Ministry of Pensions and National Insurance and by London Transport (1956) they are included with other syndromes in such a way that their prevalence cannot be determined. Yet the following "diagnoses", which occur commonly on medical certificates of absence, do not, in the opinion of the writer, necessarily represent different diseases or even always different symptoms, and are generally traumatic or auto-traumatic in origin: "strained back", "I.V.D." (inter-vertebral disc), "back injury", "lumbago", "sciatica", "backache", "sacro-iliac strain". As pointed out in the last section these back troubles are the second most common cause of sickness absence in forest workers, and the facts relating to their occurrence in the North Scottish Conservancy are detailed in Table 3.

In the syndrome of "back trouble" increasing age is an important factor (Table 4).

TABLE 4

DISTRIBUTION OF BACK TROUBLES BY AGE IN FOREST WORKERS, 1958

Age Group (years)	Population at Risk (estimated)	No. with Back Troubles	% of Population at Risk with Back Troubles
15-19	58	0	0
20-24	85	0	0
25-29	101	4	4
30-34	173	5	2·9
35-39	69	3	4·3
40-44	122	3	2·5
45-49	150	7	4·7
50-54	146	6	4·1
55-59	119	9	7·6
60-64	83	7	8·5
65-69	9	1	11·1
Total	1,115	45*	

* Age was not recorded for three workers.

Accidents.—Accidents occurring on duty in 1958 accounted for less lost time than accidents occurring off duty, a reversal of the situation in most years among the male working population as a whole. The difference was not large, however, and the total numbers of lost time accidents occurring in a single year were relatively small.

TABLE 5

ANALYSIS OF ACCIDENTS BY NATURE OF INJURY

Group and International Statistical Classification No.	No. of Spells of Absence due to On-duty Accidents	No. of Spells of Absence due to Off-duty Accidents
Burns N940-949	0	2
Fractures N800-829	2	4
Strains N839-848	15	29
Open wounds N870-898	15	7
Superficial injury N910-918	0	2
Head injury N850-856	1	1
Contusions N920-929	4	10
Unspecified injuries N996	28	16
Frostbite N980	1	0
Total	66	71

Table 5 lists the nature of the injuries received in on-duty and off-duty accidents, and Table 6 the region of the body involved. As regards on-duty accidents, it is instructive to compare these Tables with a survey of all accidents, taking place on duty (whether absence is caused or not) in a sample of the Forestry Commission's forests drawn from all conservancies. Such a sample survey is made annually by the Commission. It does not, unfortunately, follow the codings of the International Statistical Classification; but it records that open wounds, strains and sprains, and contusions are the commonest injuries in that order. The lesser frequency of open wounds and the greater frequency of sprains and strains in off-duty accidents lends emphasis to this finding and indicates the special

dangers associated with work which requires the use of axes, billhooks, etc. The Forestry Commission's survey also records the particular vulnerability of the upper and lower limbs in on-duty accidents. This is in contrast to the vulnerability of the back and the frequency of injuries to the head in off-duty accidents.

TABLE 6
ANALYSIS OF ACCIDENTS BY SITE OF INJURY

Site of Injury	No. of Spells of Absence due to On-duty Accidents	No. of Spells of Absence due to Off-duty Accidents
Head (1)	1	9
Shoulder	3	4
Arm	1	1
Hand and fingers	16	10
Back	12	18
Chest	4	8
Leg	7	3
Knee	4	5
Feet and toes	13	12
Site not stated	5	4
Total	66	74 (2)

(1) Injury to the head or face.
(2) Multiple sites in some cases.

Established Workers.—As has been stated, an establishment system is in force which allows retirement pensions to selected workers. The process of selection aims at securing from the established worker a reasonably good record of sickness absence. Table 7 indicates the extent to which this was achieved in 1958 in the north of Scotland by comparing the percentage of established workers absent as a result of certain common ailments during the year with the corresponding percentage for the labour force as a whole. It will be seen that the record of the established workers was actually better than that of the whole labour force in most respects, in spite of their being consistently older. Thus fewer established workers experienced sickness absence, and fewer were absent as a result of accident and most forms of sickness. A slightly higher percentage than average of established men was absent on account of cardiovascular illness and rheumatism and arthritis, illnesses which are both more frequent as age advances, and a higher percentage than average was absent for long spells extending over more than six weeks.

TABLE 7
ESTABLISHED WORKERS EXPERIENCING SICKNESS ABSENCE IN 1958, COMPARED WITH THE LABOUR FORCE AS A WHOLE

	Established Workers		Labour Force as a Whole	
	No.	%	No.	%
No. employed at Sept. 30, 1959	270	100·0	1,115	100·0
Average age	49 yrs 9 mths	—	34 yrs 9 mths	—
Men experiencing sickness absence	82	30·4	423	38
Two spells	12	4·5	67	6
Three spells	3	1·1	22	2
Four spells	1	0·4	4	0·4
Spells > 36 days	33	12·2	105	9·4
Spells > 72 days	16	5·9	42	3·8
No. absent due to				
Accidents on duty	4	1·5	62	5·5
Accidents off duty	13	4·8	69	6·2
Influenza	17	6·3	74	6·6
Back troubles	9	3·3	48	4·3
Septic conditions	4	1·5	24	2·2
Peptic ulcer and gastritis	4	1·5	20	1·8
Rheumatism and arthritis	9	3·3	34	3·0
Cardiovascular disease	5	1·8	16	1·4

Sickness Absence of Forest Workers compared with that of Post Office Telephone External Construction Gangs

The environmental factors that influence health are broadly divisible into those deriving from the place and nature of a man's work, and those deriving from the place and nature of his home. It would be instructive to compare the health record of two groups of highlanders, one doing forestry and one some different occupation. This has not been possible. It has, however, been possible to compare the health record of highland forest workers in 1958 with a similar sized group of men drawn from a distinctly less rural home environment doing similar work in the highland area during the same year.

The workers chosen for comparison are those who constitute the outdoor construction gangs of the Post Office telephone districts of Aberdeen and the west of Scotland. There are about 750 of these men compared with 1,115 forest workers. All these men operate in the highland area, the telephone men over a larger area than the forest workers (Fig. 1). In both occupations work is done in small, widely separated gangs supervised by a man of higher technical training, the telephone men in gangs of four or five, the foresters in gangs of variable size of about six to 20. Both groups work in the open air exposed to the full rigours of the climate. The telephone men can take shelter if necessary in their vehicles, the foresters in movable or semipermanent tilts. In the daily tasks of both groups there is a large element of sheer labouring, making considerable muscular demands, either in digging with pick and shovel, or in the manhandling of timber or rocks or apparatus. But at the same time there is a craft element in which tool work becomes progressively more skilled under the influence of repetition and native talent and the example of fellow workers. Both groups have a packed lunch at midday. The working environment of both groups is therefore similar in exposure to the elements, in liability to severe muscular strain, in packed lunches, and in the freedom from the compulsions of mass activities. Finally both groups

TABLE 8

LACERATIONS (N870-898) AMONG FOREST WORKERS AND POST OFFICE TELEPHONE CONSTRUCTION GANGS

	No. of Men	No. of On-duty Accidents	Lacerations N870-898	Lacerations as percentage of On-duty Accidents
Forest workers	1,115	62	15	25
P.O. construction gangs	776	51	3	6

are equally insulated by space and fresh air from close contact with their workmates.

There is one important difference in the working environment. The forest worker is often occupied on tasks which require cutting tools, axe, slasher, bill, saw, and the like. The tools which the telephone engineer uses are less obviously dangerous. Thus open wounds (N870-898) figure more largely among the on-duty accidents of the forester (25%) than among on-duty accidents of the post office telephone construction gang hand (6%) (Table 8).

The home environment of these two groups is very different. To express the difference quantitatively would require an elaborate social survey; but basically the difference is one of the degree of urbanization. The forest worker's home is frequently an isolated cottage or one of a pair of cottages a quarter of a mile or more from the next dwelling. Or it may be one of a group of a dozen or fewer cottages without community services such as constitutes a highland "township" or hamlet. Some forest workers live in small villages with a population of less than 1,000.

The Post Office telephone ganger normally returns home each evening, but for long periods of up to three or four months and sometimes more in a year, he may be in lodgings away from home. These lodgings may be in the villages of 1,000 population or less, but the men's homes are in towns with populations of over 2,000 and up to 200,000 such as Aberdeen, Inverness, Wick, Dingwall, Elgin, Oban, Fort William, or Tain.

TABLE 9

AGE STRUCTURE OF RANDOM SAMPLE OF FOREST WORKERS AND POST OFFICE TELEPHONE CONSTRUCTION GANGS

Age Group (years)	Percentage of Men in each Age Group of Random Sample	
	Forest Workers	P.O. Telephone Gangs
15-19	4·8	1·4
20-24	7·0	8·8
25-29	8·4	19·0
30-34	15·4	22·6
35-39	6·2	19·4
40-44	11·0	7·8
45-49	13·8	9·2
50-54	13·7	7·4
55-59	11·4	2·3
60-64	7·0	2·3
65-69	0·9	0

Two further differences between the groups must be noted. One is that only about 25% of the forest workers are established (270 out of 1,115), but about 92% (711 out of 776) of the Post Office gangs are on the establishment. In fact this constitutes less of a barrier to comparison than might be expected. There is also a considerable difference in age. The Post Office telephone gangers are much younger than the forest workers (Table 9 and Fig. 3), and to effect a fair comparison between their health records it has been necessary to allow for this.

Appendix II is a comprehensive table recording sickness absence of four days and over throughout 1958 for the commoner conditions. Columns 1-4 record the number and percentage of men absent in the whole of the two groups of workers under comparison. As noted above almost all the Post Office telephone gang hands are on the establishment, and for comparison columns 5 and 6 give the figures relating only to those of the forest workers who are established. It will be observed that both in the total number of spells of sickness absence experienced and in most of the common ailments, fewer of the foresters than of the Post Office gangers were concerned; this is true whether established men or the whole labour force is considered.

It is necessary to allow for differences in age between the two groups, and columns 7-10 show the numbers and percentage of those men under 50 in the two groups who experienced sickness absence. The better health record of the forest workers noticeable in the earlier columns is also visible here, and does not therefore depend to any great extent on the difference in age between the groups.

If it is granted that the working environment of the two groups is broadly similar in its health hazards, and that neither the difference in age nor the difference in numbers enjoying established status seem to have any notable effect on the differences in sickness absence, it is tempting to attribute the consistently better sickness record of the forest workers to some factor or factors in their home environment which may be conducive to better working health. The question of what these factors are is more easily asked than answered; but the information in columns 11 and 12 of Appendix II is at least suggestive.

Column 11 gives the ratio of the figures in column 10 to those in column 8 and expresses for the year under consideration the degree to which, for each ailment, the sickness absence record of the forest worker is better than that of the telephone gang hand. In column 12 these ratios are arranged in descending order of magnitude.

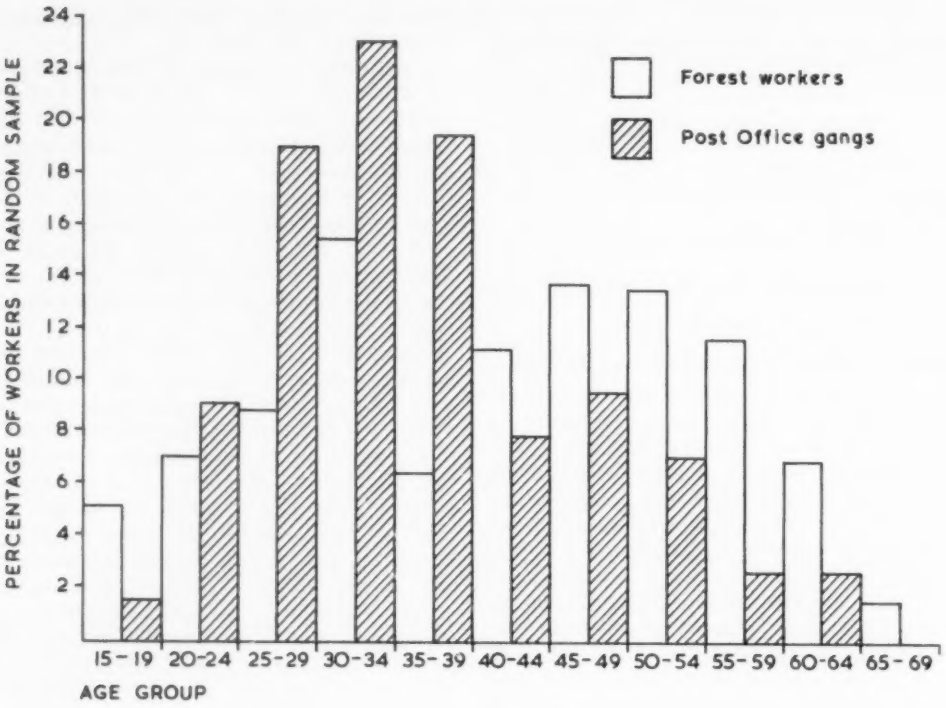

FIG. 3.—Age structure of random sample of forest workers and Post Office telephone construction gangs.

Thus in respect of bronchitis, cardiovascular disease, and peptic ulcer and gastritis in that order, the worker from the more urban home was at the greatest disadvantage. Next in order come the upper respiratory tract infections, in which the man from the more urbanized home, or perhaps it should be said the man who more frequently exchanges a more urban for a less urban environment, is at a disadvantage. Last comes a group containing accidents, septic conditions (the sequelae, perhaps, of accidents) and rheumatic and back troubles in which the difference between the sickness absence records of the two groups is least marked. It must be recognized, however, that the numbers are small. A larger group of men might well produce very different ratios.

My thanks are due to the Conservator of the North Scottish Conservancy of the Forestry Commission for access to the records of sickness absence; to the Telephone Managers of the Aberdeen and West of Scotland Telephone districts for providing the information which relates to the external construction gangs; and to the Treasury Medical Adviser for securing the essential permissions.

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APPENDIX I

SUMMARY OF ABSENCE FROM SICKNESS AND ACCIDENTS AMONG NORTH SCOTLAND FORESTRY WORKERS, 1958*

Nature of Illness	International Statistical Classification No.	1 Workers Absent		2 Spells of Absence		3 Man-days of Absence		4 Average Length of Spell †	5 Median Spell †	6 Cases Requiring Reference to Treasury Medical Adviser	7 Order of Column 3
		No.	Rate per 100	No.	Rate per 100	No.	Rate per 100				
Miscellaneous infections	001-138	4	3·58	4	3·58	183	164·0	46	22	1	26th
Benign neoplasms	210-239	4	3·58	4	3·58	243	218·0	61	16	1	20th
Allergic disorders, etc.	240-245	8	7·16	10	8·96	241	216·0	24	12	2	21st
Glandular, metabolic, and blood diseases	250-299	3	2·69	5	4·48	586	526·0	117	54	4	12th
Psychiatric illness	300-329	4	3·58	5	4·48	276	247·0	55	52	3	18th
Eye disease	370-389	3	2·69	3	2·69	39	34·9	13	16	—	31st
Ear disease	390-398	3	2·69	3	2·69	70	62·8	23	17	1	30th
Cardiac and vascular diseases	352,400-468	16	14·3	16	14·3	674	603·0	42	23	7	9th
Common cold	470	17	15·25	18	16·1	150	134·5	8	8	—	27th
Sore throat and tonsillitis	472, 473	25	22·4	25	22·4	279	250·0	11	9	—	17th
Influenza	480-483	74	66·4	79	70·8	1,438	1,288	18	12	5	3rd
Bronchitis	500-502	16	14·3	17	15·25	494	443·0	29	22	6	13th
Sinusitis, etc.‡	471, 474, 475, 490, 511-527	22	19·7	25	22·4	598	536·0	24	15	4	11th
Peptic ulcer and gastritis	540-545	20	17·9	21	18·85	699	626·0	33	20	5	8th
Appendicitis	550-553	3	2·69	3	2·69	133	119·2	44	45	3	28th
Hernia	560-561	2	1·79	2	1·79	194	174·0	97	—	2	24th
Gastroenteritis, etc.	571	14	12·55	14	12·55	344	308·5	25	11	4	16th
Other digestive diseases	530-539, 572-594	4	3·58	4	3·58	47	42·1	12	—	—	32nd
Orchitis, hydrocoele, etc.	610-637	5	4·48	5	4·48	273	245·0	55	30	2	19th
Septic conditions	690-698	24	21·5	25§	22·4	484	434·0	19	13	3	14th
Eczema, dermatitis, etc.	700-716	5	4·48	5	4·48	115	103·1	23	13	1	29th
Rheumatism and arthritis	720-727	34	30·4	36	32·3	1,304	1,170	36	18	7	5th
Synovitis, internal derangement of the knee joint, etc.	730-749	18	16·1	18	16·1	602	540·0	33	16	6	10th
Chill and pyrexia of unknown origin	788	17	15·25	17	15·25	204	183·5	12	9	—	23rd
Pleurodynia	783	3	2·69	3	2·69	194	174·0	65	74	2	24th
Neuritis and sciatica	360-366	13	11·65	16	14·3	710	636·0	44	20	5	7th
Urinary disease	600-605, 786-789	5	4·48	5	4·48	239	214·5	48	34	2	22nd
Miscellaneous other conditions		27	24·2	30	26·9	1,187	1,063	40	22	11	6th
Accidents on duty	N800-999	62	55·6	66	59·1	1,347	1,205	20	14	9	4th
Accidents off duty	N800-999	69	61·9	71	63·6	1,729	1,545	24	16	13	1st
Unknown		16	14·3	16	14·3	399	357	25	8	3	15th
Back troubles	723, 726, 735, 787, 363, N846, N847, N996	48	43·1	51	45·7	1,464	1,313	29	16	9	2nd

NOTES:
* Excluding uncertificated absence of three days or under. † To the nearest day. ‡ Mainly sinusitis, tracheitis, and laryngitis.
§ 15 of these appear to have derived from external injury.

APPENDIX II

COMPARISON OF THE SICKNESS ABSENCE EXPERIENCE OF POST OFFICE TELEPHONE EXTERNAL CONSTRUCTION GANGS AND NORTH OF SCOTLAND FOREST WORKERS, 1958

	International Statistical Classification No.	Post Office Gangs		Forest Workers		Established Forest Workers		Forest Workers age <50		Post Office Gangs age <50		11 Column 10 / Column 8	Order of Magnitude of Column 11
		1	2	3	4	5	6	7	8	9	10		
		No	%	No.	%	No.	%	No.	%	No.	%		
Number in group	—	776	100·0	1,115	100·0	270	100·0	758	100·0	683	100·0		
Men experiencing sickness absence	—	359	46·2	423	38·0	82	30·4	317	41·6	313	45·5		
Two spells	—	83	10·7	67	6·0	12	4·5	32	4·2	68	10·0		
Three spells	—	18	2·3	22	2·0	3	1·1	8	1·1	17	2·5		
Four spells	—	3	0·4	4	0·4	1	0·4	2	0·3	2	0·2		
> six weeks' continuous absence	—	39	5·0	105	9·4	33	12·2	43	5·7	27	4·0		
> 12 weeks' continuous absence	—	15	1·9	42	3·8	16	5·9	16	2·1	7	1·0		
No. absent due to													
Accidents on duty	N800-999	51	6·6	62	5·5	4	1·5	32	4·2	45	6·6	1·57	12th
Accidents off duty	N800-999	73	9·4	69	6·2	13	4·8	37	4·9	62	9·1	1·86	8th
Accidents (all sorts)	N800-999	124	16·0	131	11·7	17	6·3	69	9·1	107	15·7		
Back troubles	363, 726, 735, 787, 723, N846, N847, N996	41	5·3	48	4·3	9	3·3	22	2·9	35	5·1	1·76	11th
Rheumatism and arthritis	720-727	33	4·3	34	3·0	9	3·3	17	2·2	28	4·1	1·86	9th
Influenza	480-483	78	10·2	74	6·6	17	6·3	35	4·6	72	10·1	2·2	5th
Common cold	470	26	3·4	17	1·5	1	0·4	11	1·5	23	3·4	2·26	4th
Tonsillitis	272, 473	23	3·0	24	2·1	—	—	13	1·7	22	3·2	1·88	7th
Bronchitis	500-502	16	2·1	16	1·4	2	0·8	2	0·3	11	1·6	5·35	1st
Respiratory complaints	470-527	166	21·4	150	13·4	24	8·9	70	9·3	149	21·8		
Septic conditions	690-698	23	3·0	24	2·1	4	1·5	14	1·8	22	3·2	1·77	10th
Peptic ulcer and gastritis	540-545	29	3·7	20	1·8	4	1·5	11	1·5	25	3·7	2·46	3rd
Cardiac and vascular diseases	352, 400-468	8	1·0	16	1·4	5	1·8	2	0·3	8	1·2	4·0	2nd
Gastroenteritis	571	15	1·9	14	1·3	1	0·4	10	1·3	13	1·9	1·46	13th
Chill and pyrexia of unknown origin	788	18	2·3	17	1·5	5	1·8	10	1·3	18	2·6	2·0	6th

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ECOLOGICAL FACTORS AFFECTING EFFICIENCY AND HEALTH IN WARSHIPS*

BY

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The environment of those who live and work in warships is closely related to the way the ships are built and employed. In stating the requirements for the atmosphere between decks the emphasis has swung during the past 50 years from the need for controlling the chemical constituents to the control of the factors which comprise the thermal environment, and now, with the advent of the nuclear-powered submarine, to the need for achieving, as nearly as possible, complete physical, chemical, and microbiological control.

Between 1944 and 1953 the thermal factors between decks were investigated in a series of studies carried out in H.M. Ships. The average effective temperatures on the mess decks and in the work places of 11 ships in the Eastern Fleet in 1944 exceeded 84°F. (28·9°C.). In compartments where radiant heat was an added factor the average corrected effective temperature levels were 1° or 2°F. (0·55-1·1°C.) higher than the corresponding effective temperatures.

The effects of climatic conditions on naval personnel were investigated by psychological studies to determine the levels of warmth at which performance deteriorated; by physiological experiments to show the levels of warmth at which the collapse of men working at different work rates might be expected; by comfort surveys in ships and on shore to determine the levels of warmth at which the majority enjoyed optimum comfort; and by relating the monthly incidence of the common causes of ill-health to the average monthly upper-deck temperature as recorded at noon each day in order to determine the temperature level above which sickness increased. It was concluded that the upper desirable level of warmth to consider when designing ships for hot climates was an effective temperature of 78°F. (25·5°C.).

As it is usually impracticable in many compartments to achieve temperatures below 78°F. (25·5°C.) in the tropics without the generous application of air cooling, attention was then directed to the associated effects on the chemical and bacterial constituents of restricting air supplies, an unavoidable feature of most air conditioning systems, and to defining the permissible lower limits for fresh air requirements.

The nuclear submarine with its capacity for remaining submerged for very long periods raises new problems relating to life in a confined space and involving very prolonged exposure to the submarine environment. These problems have still to be investigated.

The factors which are necessary to provide warships' companies with an equable environment in which to live and work can be discussed conveniently if we keep in mind the changing emphasis which has guided policy in recent times. Until about 400 years ago, or even after that time, men tended to live on ships rather than in them. Sir Walter Raleigh made the terse comment "cabins are but sluttish dens that breed sickness" (Shaw, 1929); and the despatches of the Lord High Admiral of the English Fleet, Howard of Effingham, contain ample evidence that the hygienic state of the ships which awaited the onslaught of the Spanish Armada in 1588 was truly deplorable. After the Tudor period the main improvements were to keep ships and ships' companies clean by scrubbing decks, washing clothing (the issue of soap was a revolutionary advance), by issuing clean clothing, by isolating the sick, and by employing wind sails, wind scoops, and other devices to convey air below.

The most notable devices were the "blowing wheel" of Desaguliers worked by men whom he

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† Surgeon Captain, Royal Navy.

called "ventilators", with which he first ventilated the House of Commons early in the eighteenth century (Desaguliers, 1727; 1735), the hand-worked bellows devised shortly afterwards by the country clergyman and biologist Stephen Hales (Clark-Kennedy, 1929; Hales, 1755) and convection pipes leading from ships' galley fires which were invented by a brewer, Samuel Sutton (Bernan, 1845). It is a sombre thought that these developments were motivated not only by the need for keeping mariners in fighting trim, but also by the requirement of the merchants of the slave trade between the Guinea Coast and the plantations in the Americas to preserve their human cargoes in a saleable condition. All these methods had their successes in the Navy, but only in the face of hidebound conservatism. Thus Sutton drolly remarked (Bernan, 1845) "I particularly remember that, being at a coffee house near the Admiralty, I placed myself nigh some gentlemen of the Navy and enquired of them, as I had before of others, as to the usefulness of a change of air: all, to a man, acknowledged it would be of the utmost service. I told them I could procure it; upon which one of the company went to another table, and the rest followed him; and I heard him tell the others that he heartily pitied me as being really mad and out of my senses". One does not read much about the thermal environment in the journals of those days, for infectious disease and nutritional deficiencies swamped nearly all other considerations of medical importance. In addition, the wooden sailing ships did not generate the vast quantities of heat which must be dissipated from ships propelled by power plants.

When it became possible to supply air with power-driven fans in the latter half of the nineteenth century it was not therefore surprising that interest centred at first on preserving the chemical composition of the atmosphere near to that of atmospheric air about which a great deal had been learnt in the previous 100 years. It was required of the designer that the ventilation arrangements should maintain the proportion of carbon dioxide in the air below 0·06%, only 0·02% in excess of the proportion in the outside air. Even in 1914, when an Admiralty Ventilation Committee (1914) reported, this exacting requirement was only relaxed to 0·07%. By this time, however, a new factor was already making itself felt, namely, excessive environmental warmth, an undesirable waste product of the ever more powerful propulsion machinery. This factor became increasingly prominent during the First World War, which was fought mostly in northerly or temperate waters. The situation was aggravated in the years that followed by the addition of more and more defensive and offensive equipment, which called for increased generating power, and the need for even greater propulsive power, and which together led to a corresponding increase in what came to be called "wild heat". When, therefore, in 1938 another Admiralty Ventilation Committee (1938) rendered its Report, the carbon dioxide criterion was abandoned. New standards, which aimed at the control of compartment warmth rather than chemical purity of air, were accepted. An air temperature of 15·5-18·3° C. was recommended for cold climates and the requirements in tropical or sub-tropical waters were not discussed in detail. "Air-conditioning", or air-cooling, was not considered essential.

Events in the second world war soon proved that submarines could not carry out repeated war patrols in the tropics without air-cooling machinery and towards the end of the war British submarines operating in tropical waters were effectively air conditioned—a convincing demonstration of the primary importance of providing adequate means for controlling the full ranges of conditions likely to be encountered in warfare under environmental extremes. Strongly worded reports from the Commanders-in-Chief of the relatively small British forces which were at first maintained in the East also stressed the difficulties of preserving the health and efficiency of the crowded ships' companies of surface ships, as well as submarines. This was brought home in 1943 and 1944 when the greater part of the British Fleet, hitherto occupied in more temperate waters, began to congregate in the Indian Ocean. There were serious misgivings as to whether the ships could remain closed up during a prolonged action without crippling loss of fighting efficiency. These doubts were never really answered, for the atomic bomb stopped the war before any further conventional battle fleet action in the grand style (as opposed to aircraft carrier action) could be fought in the tropics. When hard work had to be done heat stress did not only raise problems in tropical climates. The rate of fire was limited in temperate or even in northern waters by the effects of heat stress on the gun turret crews.

Early in 1944 at the request of the Admiralty a sub-committee was appointed by the Medical Research Council's Royal Naval Personnel Research Committee to examine the effects of climate and other environmental factors on fighting efficiency. This sub-committee commenced its task handicapped by an incomplete knowledge not only of the conditions in the Fleet, but also by a lack of information concerning the levels of warmth which might be expected to impair physiological or psychological efficiency, health or comfort. Such knowledge as was available had mostly been obtained in

empe rate climates, and the views of the experts varied widely on whether or not this could be applied to men who would be partially or completely acclimatized to air temperatures far in excess of those at which workers in hot industries in temperate climates lived when they were not at work.

The five-pronged attack on the tropical problem which followed was ambitious and, although it was surprising how much it was possible to contribute to the practical problems of the day, it was only gaining momentum by the time the war ended. The first group of investigators measured the climatic conditions between decks in action and when cruising in the Eastern and British Pacific Fleets, and evaluated the effects on the men. The second group, at the National Hospital for Nervous Diseases, Queen Square, London studied the physiological effects of hard work, such as guns' crews had to perform, on men wearing action working dress during four-hour watches at high temperatures. The third group, in the Psychology Department at the University of Cambridge, examined the effects of various levels of warmth on the performance of naval ratings carrying out tests which were based on the semi-skilled activities of wireless telegraphy or radar operators, or men carrying out manual tracking tasks in weapon control systems. These physiological and psychological studies were essentially exploratory studies, on men who were "artificially acclimatized" by repeated daily exposure to work at high temperatures, designed to develop techniques which could be applied later to "naturally acclimatized" men in the tropics. The tropical phase of the work was delayed until 1948. A well-equipped Climatic Laboratory was established by then in the grounds of the King Edward VII Medical College, Singapore and laboratory studies were continued there until 1953. The fourth approach was to relate sensations of thermal comfort to temperature, humidity, and air movement conditions in living spaces or offices in ships and on shore with a view to identifying the levels of warmth at which most individuals thought they were thermally "comfortable" rather than "too warm" or "too cool", and those at which perceptible sweating commenced. In the fifth series of investigations the sickness rates were compared in ships and on shore in the tropics and in ships operating in temperate and in tropical climates. The monthly rates, as determined from figures reported weekly by all ships of the Fleet, were related to the average monthly upper-deck temperature recorded at noon each day between 1948 and 1952, to show the levels of ambient air temperature at which there was evidence of increasing ill-health.

It is necessary to discuss briefly the methods which can be employed for measuring warmth. The factors to be considered were the air temperature, humidity, air speed, the mean radiant temperature of the surroundings, the work rate, and clothing.

The methods of measurement shown in Table I were evolved either from comfort studies (1), (2) or physiological studies (3) in climatic laboratories, or as a result of evaluation in the field of the conditions under which men were found to collapse under training or during operations (4). The effective temperature scales, developed by Yaglogou, Houghten, and their colleagues (Houghten and Yaglogou, 1923, 1924; Yaglogou and Miller, 1925), for the American Society of Heating and Ventilating Engineers over 30 years ago and adopted by the United States Navy, were chosen as the most convenient method for use in the Royal Navy during the war.

TABLE I

(1)	EFFECTIVE TEMPERATURE—derived by applying the dry-bulb and wet-bulb temperatures and air speed to a "basic" chart for persons stripped to the waist or a "normal" chart for light clothing. For evaluating the conditions conducive to comfort indoors of sedentary or lightly occupied persons in compartments where radiant heat *is not* a factor. (Used in Royal Navy and U.S. Navy.)
(2)	"CORRECTED" EFFECTIVE TEMPERATURE (BASIC OR NORMAL)—derived by applying the globe and wet-bulb temperatures and air speed to the same charts. For compartments where radiant heat *is* a prominent factor. (Used in Royal Navy.)
(3)	PREDICTED FOUR-HOUR SWEAT RATE (P4SR)—derived by applying dry-bulb, wet-bulb and globe thermometer temperatures, air speed, work rate and an estimate of the amount of clothing worn to the P4SR nomogram. For evaluating the stress imposed by warm climates with varying work rates.
(4)	WET-BULB GLOBE THERMOMETER INDEX (WBGT)—derived from 0·7 of wet-bulb temperature (in sun and wind) + 0·2 of globe temperature (in sun and wind) + 0·1 of dry-bulb temperature (shade). For defining conditions outdoors which call for modification of training programmes. (Recommended for U.S. Armed Forces.)

There are two scales or charts, "basic" and "normal", which relate to sedentary persons stripped to the waist or clad in light indoor clothing. The "effective" temperature is "the temperature of still air saturated by water vapour in which an equivalent sensation of warmth (to that experienced at the air temperature, humidity and air speed under investigation) would be experienced by the average individual". For example, according to the "normal" chart, with an air temperature of 26·7°C. a wet-bulb temperature of 26·7°C., and an air speed of 20 ft. per min. (virtually still air) the effective temperature is 26·7°C. But, also, with an air temperature of 35°C., a wet-bulb temperature of 21°C. and an air speed of 200 ft. per min. the effective temperature is still 26·7°C.; that is to say a man would be equally comfortable in either environment. These charts were constructed to indicate the effects on comfort of variations in air temperature, humidity and air movement only. To allow for radiant

heat, when necessary, it was recommended by Bedford (1946) that the readings of Vernon's black globe thermometer be employed in place of those of the dry-bulb thermometer when the charts were used, to give a "corrected effective temperature". It was stated that effective temperatures (corrected, normal, or basic) of 26·7°C. should not be exceeded in the tropics and that when 30°C. was exceeded some loss of efficiency, discomfort or ill-health would have to be accepted.

An important omission from the effective temperature charts, was that there was no correction for work rate. This was partially overcome by a stratagem devised at the National Hospital by Dr. Brian McArdle and his colleagues (McArdle, Dunham, Holling, Ladell, Scott, Thomson, and Weiner, 1947; Smith, 1955). From a rather more complicated and empirical nomogram, constructed from their experimental data, the "predicted four-hour sweat rate", or the "P4SR" to which this rather cumbersome term was abbreviated, can be determined. In their view an index based mainly on the sweat rate provides the best guide to the stress imposed by different hot environments, and this has provided the basis for the development of further new indices, notably that introduced by Belding and Hatch (1955) to which there is not space to refer further here. "P4SR values" can be obtained from this nomogram, provided the dry-bulb, wet-bulb and globe temperatures, the air speed, the energy cost of the activity under investigation, and the clothing worn are known.

One other stress index, recently introduced in the United States of America, should be mentioned, the "WBGT Index" or the "wet-bulb globe-thermometer index". The "WBGT" is obtained from the sum of 0·7 of the wet-bulb temperature exposed to sun and wind, 0·2 of the globe thermometer temperature similarly exposed and 0·1 of the dry-bulb temperature in the shade. Guidance is given in United States Army Technical Bulletin, Medical 175 and corresponding United States Navy and Air Force Instructions (United States Army, 1957) for its use in limiting training procedures during hot weather. It is more simple to use than effective temperature, especially if observers are not fully trained. A useful by-product of its acceptance trials was that it was found that Bedford's corrected effective temperature could be used for forecasting conditions likely to cause incapacitation out of doors as well as indoors or between decks and that it was at least as reliable as the WBGT Index when used in this way (Minard, 1958).

The findings of these studies in terms of effective temperature and predicted four-hour sweat rate were the subject of numerous domestic reports to the Medical Research Council's Royal Naval Personnel Research Committee and were summarized in a series of review papers and lectures as they became available (Critchley, 1945; Ellis, 1947, 1948; 1950; 1953a; 1954; 1955). The psychological studies in England were published by Mackworth (1950; 1948). The psychological studies at Singapore have been summarized in reports to the Royal Naval Personnel Research Committee and published by Pepler (1953, 1954 and 1958). A compilation of the principal reports in the physiological series is being prepared for publication by the Medical Research Council and should be available in 1960. Points of naval interest were as follows:

1. The average effective temperatures on the mess decks and in the work places of 11 ships of the Eastern Fleet, shown in Table 2, were always in excess of the recommended 26·7°C. and frequently exceeded the "upper tolerable level" of 30°C.

In those compartments where radiant warmth was an added factor, and in which globe thermometer measurements were made, the situation was even less satisfactory (Table 3), although the added stress due to this factor was not as great as was expected before the survey was undertaken, except perhaps in galleys.

These average effective temperatures, for which the warship designer must cater when he makes provision for climate control at the upper end of the temperature scale, may be kept in mind as the evidence concerning the effects of warmth on personnel is reviewed.

2. According to the psychological tests sedentary watchkeepers, stripped to the waist and engaged on semi-automatic semi-skilled work, such as morse code reception, are less efficient when the basic effective temperature is somewhere between 27·2°C. and 30°C. provided they are "naturally" (Pepler, 1953, 1954, 1958) or "artificially" (Mackworth, 1950, 1948) acclimatized to working at this level of warmth. The normal effective temperatures for men wearing naval working dress would be distinctly lower (probably of the order of 0·55 or 1·1°C. or perhaps even more). Unacclimatized men were not studied.

3. The physiological studies indicated that, under the highly artificial conditions of these experiments, some fit and trained young men may be incapacitated when the environmental conditions are such that the "P4SR" value would exceed 4·5, again provided that they were either "naturally" or "artificially" acclimatized to working under the conditions in question, whether they were living in the tropics or in a temperate climate when they were not at work (Irwin, 1956; McArdle *et al.*, 1947). Dry- and wet-

TABLE 2

AVERAGE NORMAL EFFECTIVE TEMPERATURES IN 11 SHIPS OF THE EASTERN FLEET, 1944

Compartment	Normal Effective Temperature (°C.)	Dry-bulb Temperature (°C.)	Wet-bulb Temperature (°C.)	Air Speed (ft./min.)	No. of Observations
Mess decks (living spaces)	28·9	32·2	27·7	100	947
Machinery spaces	31·5	39·2	31·0	468	359
Gunnery control positions	30·2	35·3	29·0	172	364
Gun turret lower quarters	30·3	33·2	29·4	60	125
Radar offices	30·5	36·5	28·7	160	59
Electrical spaces	32·0	40·3	28·1	147	81
Workshops	30·8	37·9	28·7	193	55
Sick bays	28·3	32·7	27·8	239	82
Communication offices	29·9	35·5	28·8	163	168
Galleys	30·8	36·3	29·0	192	168

TABLE 3

AVERAGE NORMAL EFFECTIVE TEMPERATURES AND CORRECTED EFFECTIVE TEMPERATURES SHOWING THE EFFECT OF "WILD HEAT"

Compartment	Normal Effective Temperature (°C.)	Corrected Effective Temperature (°C.)	Mean Radiant Temperature (°C.)	No. of Observations
Engine rooms	31·4	32·4	53·9	116
Boiler rooms	30·2	31·0	48·7	59
Gearing rooms	30·8	31·8	42·4	62
Electrical spaces	31·8	32·4	46·0	50
Galleys	30·6	32·2	54·4	125
Workshops	30·8	30·7	42·0	36
Radar offices	29·7	30·3	38·1	73
All observations	30·8	31·7	48·2	519

TABLE 4

THE UPPER "TOLERABLE" LEVELS OF WARMTH CORRESPONDING TO A P4SR LEVEL OF 4·5 FOR MEN LIVING IN A TEMPERATE CLIMATE BUT ACCLIMATIZED TO WORK AT HIGH TEMPERATURES EITHER AT WORK (100 kcal./m.²/hr.), OR AT REST (54 kcal./m.²/hr.), FOR FOUR HOURS WEARING NAVAL OVERALLS; AS DERIVED FROM THE "P4SR" NOMOGRAM (McARDLE *et al.*, 1947)

Dry-bulb temperature	°C.	33·8	35	37·7	40·5	43·7	46·1	48·8	51·6	54·4
Corresponding wet-bulb temperature for "working" men	°C.	32·5	32·4	32·3	32·1	31·9	31·8	30·2	27·3	*
Corresponding wet-bulb temperature for "resting" men	°C.	—	*	35·5	35·4	35·3	35·2	35·0	30·5	31·1

Air speed 150 ft./min. (76 cm./sec.)
* Outside range of nomogram.

TABLE 5

UPPER "TOLERABLE" EFFECTIVE TEMPERATURES (°C.) CORRESPONDING TO A P4SR LEVEL OF 3 FOR MODERATELY ACTIVE (100 kcal./m.²/hr.) ACCLIMATIZED YOUNG MEN DURING A FOUR-HOUR WATCH WEARING OVERALLS OR SHORTS*

Mean Air Speed ft./min. (cm./sec.)	Men Wearing Overalls				Men Wearing Shorts†			
	Dry-bulb Temperatures °C.				Dry-bulb Temperatures °C.			
	32·2	37·7	43·7	48·8	32·2	37·7	43·7	48·8
20 (10)	30·9	31·5	30·65	—	31·6	32·5	32·5	—
100 (51)	31·1	32·1	31·3	—	—	33·0	33·3	—
300 (152)	—	31·7	29·3	—	—	32·7	32·8	—

* The observed energy cost of the same working routine was 111 kcal./m.²/hr. in London but only 100 kcal./m.²/hr. in Singapore, a difference which has not been explained satisfactorily. The P4SR's here were calculated for 100 kcal./m.²/hr., and would be slightly more for 111 kcal./m.²hr.
† The higher basic effective temperatures for men wearing shorts emphasizes that the normal and basic scales are not interchangeable.

bulb temperatures corresponding to this value are given in Table 4.

4. However, when allowance is made for all the variables which must be considered in a warship in time of war, and in particular for variations between individuals and for the fact that men are frequently neither naturally nor artificially acclimatized to the levels of warmth at which they may be called upon to work (Hellon, Jones, Macpherson, and Weiner, 1956; McArdle *et al.*, 1947; Weiner and Macpherson, 1956), effective temperature levels which correspond to a P4SR value of 3 may be expected to cause incapacitating heat illness at times. Effective temperatures of this order, for men engaged in moderately active work wearing light or very light clothing are shown in Table 5 to be usually above 30°C., but if the work were more strenuous or the clothing heavier or less permeable the limiting effective temperature would be appreciably lower in proportion to the additional stress imposed and might well be less than 30°C. in certain circumstances.

The low value of 29·3°C. is probably misleading and due to a constructional fault in the lower ranges of the P4SR nomogram.

5. The majority of acclimatized men living in ships or on shore in the tropics are reasonably comfortable in relation to their thermal environment provided the effective temperature does not exceed 25·5°C. or fall below 22·8°C. (Ellis, 1952b; 1953c). In northern waters most men are reasonably comfortable by day and night when the air temperature is between 15·5 and 18·3°C. (Pugh, 1949) as the Admiralty Ventilation Committee (1938) observed. This wide contrast with the tropical comfort zone is explainable in terms of the increased amount of clothing worn and differences in acclimatization.

6. Minor illnesses, particularly skin diseases, increase when the average monthly upper-deck temperature recorded at noon exceeds 26·7°C. (Ellis, Smith, and Underwood, 1953; Smith, 1955) which corresponds approximately to effective temperatures on the mess decks of about 26·7°C. Fig. 1 indicates the percentages of ships' companies who were on the "attending list" with minor disorders during the years 1948-1952 in relation to the average monthly upper-deck temperature as recorded at noon each day. Skin diseases contributed largely to the rise in ill-health with upper-deck temperatures above 26·7°C. There was no notable change at the cold end of the temperature scale.

7. We find that men living in warships in the tropics without air cooling for more than six months at a time under operational conditions (where we have seen that the average effective temperatures are likely to be 28·9°C. or higher (Table 2) are likely to develop symptoms of hot-climate or tropical fatigue (Ellis, 1952a, 1953b; Macpherson, 1949). This is typified by

> "lethargy, mental retardation, reduced powers of concentration and sense of responsibility, irritability, and mild changes in personality and forgetfulness, which are associated often with excessive sweating, unsatisfactory sleep, skin disease, loss of weight, loss of appetite, and ill-defined digestive disorders. This syndrome develops when men live and work at levels of warmth which result in the presence of unevaporated sweat on the skin and in the clothing or bedding. The majority of men exposed to these conditions will suffer in one way or another after a time, but in a healthy community serious breakdown will not be encountered very often, and there will be little reference to the condition in routine sickness returns. Most of these effects can be surmounted temporarily when it is necessary to make a special effort, and are relieved by resumption of life in a cooler climate" (Ellis, 1952a).

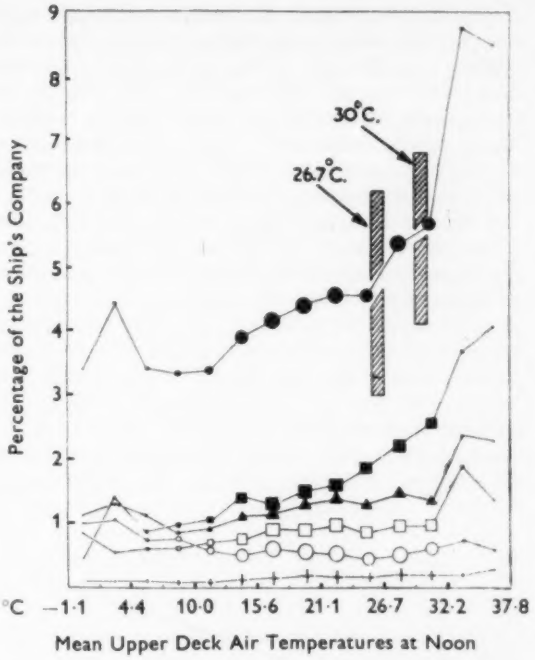

FIG. 1.—Percentages of the ship's company on the attending list and the mean upper-deck air temperature at noon. (After Smith, 1958) ● total; ■ skin disease; □ injuries; ○ respiratory infection; + dysentery; ▲ all other. (The area of each point plotted in the diagram is proportional to the number of monthly returns from which the average value was calculated.)

Hot-climate fatigue can stand as a clinical entity on its own when encountered in an otherwise healthy community living and working in an excessively warm environment. It should be distinguished from the so called tropical neurasthenias, in the causation of some of which excessive warmth may play only a minor role, and from those conditions designated as heat exhaustion.

8. Thus the main finding, particularly from the studies on comfort, and sickness incidence, is that the upper desirable level of warmth to keep in mind in ship design for hot climates is an effective temperature of 25·5°C. This is the Admiralty policy (Sims, 1945) and, it is believed, that of the United States Navy. Heating arrangements should be sufficient to provide air temperatures in living and working compartments between 15·5 and 18·3°C. in northerly or southerly waters (Admiralty Ventilation Committee, 1938; Pugh, 1949). These figures indicate the range to which we think the ship constructor should work.

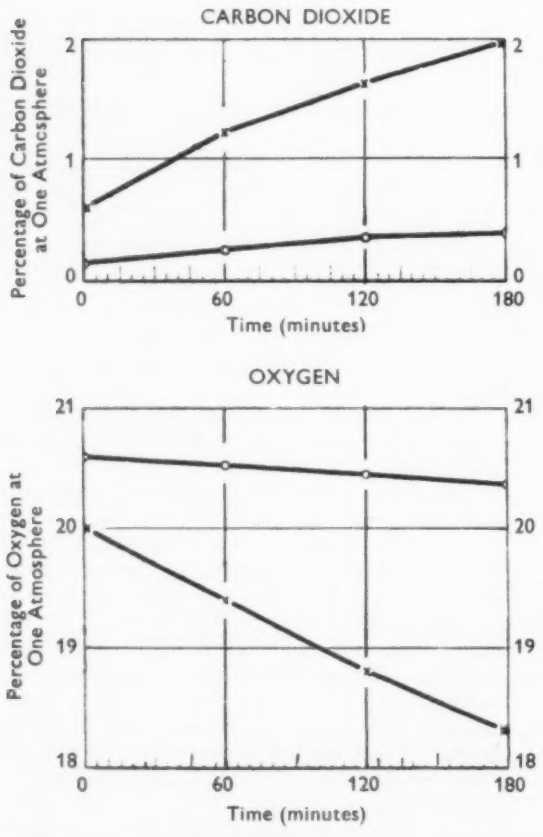

FIG. 2.—Carbon dioxide and oxygen content of the air in a sparsely occupied non-air-conditioned living space and in a crowded air-conditioned working space of a ship closed down.
-x- working space; -o- living space.

It is not usually practicable to maintain effective temperatures between decks in the tropics below 25·5°C., or in warm weather elsewhere when ships are closed down for action, unless the air is cooled and moisture extracted from it by a system which can only be operated economically when the spaces so treated are completely enclosed and carefully insulated to prevent them taking up heat from hot surroundings and when the fresh air supplies are restricted to the minimum compatible with health. These considerations have directed attention to associated effects on the chemical and bacterial constituents of the atmosphere and the permissible lower limits for fresh air requirements.

The manner in which oxygen decreases and carbon dioxide builds up is shown for a crowded working space and a sparsely occupied living space in a cruiser under closed-down conditions (Fig. 2). If the conditions in this working compartment were maintained for more than a few hours the fresh air supply would have to be re-established or equipment for releasing oxygen and removing carbon dioxide would have to be provided, unless the alternative of maintaining a fresh air supply, filtered to remove potentially harmful agents, were acceptable. In submarines, carbon dioxide levels may be in the region of 3% and mild anoxia may be unavoidable at the end of a long day's dive if nothing is done to restore the atmosphere. At levels of this order some men experience mild headaches and a disinclination for work and others may report "off-effects", nausea or vomiting, lassitude, and general malaise, on regaining the fresh air after surfacing, particularly if they are passengers who are unaccustomed to breathing air with a high carbon dioxide content.

The same effects are to be expected in air-conditioned compartments if the air is completely re-circulated without any fresh air dilution; this is also an added complication of closing down gun-turret lower quarters completely for long periods. The oxygen depletion and carbon dioxide accumulation can be estimated approximately provided the size of the compartment and the number of occupants are known. A man doing light work requires 1·1 cu. ft. (0·033 m.^{3}) of oxygen and exhales about 1 cu. ft. (0·03 m.^{3}) of carbon dioxide per hour; with hard work these figures may be quadrupled. It is surprising how soon a crowded, enclosed compartment can become untenable for this reason alone.

Investigations of the bacterial content of the air in a cruiser and a submarine were carried out towards the end of the war (Ellis and Raymond, 1948). Counts of bacteria-carrying particles which exceeded 50/cu. ft. (1,760/m.^{3}) were at that time

considered undesirable by the air hygiene experts, and in most of the compartments of the cruiser this level was not exceeded, except when there was much activity on the mess decks. The air in the submarine was remarkably free from bacteria-carrying particles whether it was submerged or on the surface, probably because the particles adhered to the ventilation ducting or to oily surfaces. The micro-organisms in the air samples were nearly all non-pathogenic, or of very low pathogenicity. However, the bacteria-carrying particle count does provide a measure of the micro-organism-carrying potential of the ventilation system, which can be greatly reduced by measures for eliminating dust and reducing the particle content of the air.

Tests undertaken for a few hours in an air-conditioned space in the cruiser and in a climate controlled room in London indicated that a build up of bacteria-carrying particles in the air did not occur even when the air was completely re-circulated, probably for similar reasons to those which controlled airborne particles in the submarine. A more recent study confirms this finding for complete re-circulation for periods of 24 hours. More extended trials are desirable.

The minimal supplies of fresh air which will permit men to live a comfortable, healthy, and efficient existence in an enclosed space are thus influenced by a variety of factors. Unrestricted heavy tobacco smoking causes malaise, headaches, and upper respiratory tract irritation. With air cooling, 5 cu. ft. (0·15 m.^{3}) of air per man per minute is sufficient to keep body and tobacco odours at acceptable levels (Consolazio and Pecora, 1946). With activated carbon filters and air cooling even 1 cu. ft. (0·03 m.^{3}) per man per minute is adequate. In the United States Navy a fresh air supply of 5 cu. ft. (0·15 m.^{3}) per man per minute is the minimum required by design for air-cooled compartments, although for other reasons, this amount is usually exceeded in practice. In the Royal Navy at least 10 cu. ft. (0·3 m.^{3}) per man per minute is supplied to air-cooled compartments when the cooling is in operation. For compartments with normal ventilation an allowance of 10 cu. ft. (0·3 m.^{3}) per man per minute is added to the amount which is calculated to be necessary to get rid of the heat within the compartment. The total quantity must be equivalent to at least 30 cu. ft. (0·9 m.^{3}) per man per minute (Admiralty, 1946).

There are, of course, some compartments which it is not possible to "air-cool" and which may become intensely warm when the ventilation system is closed down, such as certain machinery spaces. Reliance must then be placed either on air-ventilated or air-cooled suits or cubicles, the design requirements of which are influenced by the duration and type of work which must be done, or on the alternative of relieving watchkeepers very frequently and within the period known to be endurable for the work, clothing, and temperature conditions imposed.

The most recent "enclosed space" which challenges the naval hygienist is the submarine powered with a nuclear reactor. Lieutenant Commander John H. Ebersole, Medical Officer of the United States Submarines, Nautilus and Seawolf, gave a fascinating glimpse, in an address to the Royal Society of Medicine in London in December 1957 (Ebersole, 1958), of the complex situation with which he and his technicians and the submarine designers have had to contend, and of the success their efforts have achieved. The remarkable control of the radiation environment and the completeness of his records for every man in the crew suggest that the United States Navy has already learnt the lesson of how to live all day and every day in the close vicinity of a powerful nuclear reactor with complete radiological safety, acquired as a result of careful training, a thorough understanding of the problem, constant vigilance (24 hours a day), and superlative engineering design. The 60-day underwater cruise of the U.S.S. Seawolf has since been undertaken and the second instalment of this story is eagerly awaited.

Repeated submarine patrols, completely submerged for 60 days or more, are now a feasible proposition. It seems that only limitations imposed by human factors can stay the development of naval operations in this area. Many of the practical answers can only be obtained in the submarine. When a normal constituent of the atmosphere such as carbon dioxide, is present in abnormally high amounts, only time can indicate whether such effects as readjustment of the acid-base balance are acceptable adaptations or unacceptable effects which may be harmful. When gross atmospheric impurities, such as excess carbon dioxide or monoxide, are removed the possibility still remains that very prolonged and repeated exposure to minute traces in the air of volatile components or breakdown products of refrigerants, tobacco, fuels, lubricants, solvents, cooking fats, paints, plastics, or even of products of the human body itself, most of which in the past have usually been ignored, may in some way prove harmful.

There may be less tangible considerations. At the International Congress of Tropical Medicine at Lisbon in 1958 Professor C. D. de Langen of the Netherlands referred to the effects of variations in the electrical charge of the atmosphere on feelings of well-being and on the relative severity of the symptoms of climate-sensitive patients he had

observed in the Netherlands' Indies many years ago (De Langen, 1934). Recent work in the United States and Russia also suggests that this factor may have to be taken into serious consideration by air hygiene experts.

The basic information which is needed to deal with the enclosed space of the submarine has, of course, applications elsewhere in the design of underground or underwater shelters, depots, control points, or headquarters, or, if one gazes more deeply into the crystal, in space ships or world satellites. These considerations go far beyond the single discipline of environmental hygiene. Environmental medicine is perhaps a better term to describe the very broad approach which is required.

It is concluded that, although much has been learnt about the naval environment and others like it since our forefathers first sailed east and west to the Indies, the demands today for accurate design data and information concerning the ways in which new environmental situations may affect those exposed to them are probably as heavy as they have ever been. There is still much more to be learnt.

This paper is published by permission of Surgeon Vice-Admiral Sir Cyril May, K.B.E., C.B., M.C., Q.H.S., F.R.C.S., Medical Director-General of the Navy, and of Major-General William H. Powell, Jr., United States Air Force (Medical Corps), Chief Medical Officer, Supreme Headquarters Allied Powers, Europe.

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BOOK REVIEWS

Radiation Hygiene Handbook, 1st ed. Editor in Chief: Hanson Blatz. (Pp. xi + 928 + Index, illustrated. £10 13*s.* 0*d.*) London: McGraw-Hill Book Company. 1959.

So rapid has been the growth of the many fields of atomic energy during the past 10 years, that it is well nigh impossible to know what is being done in the numerous disciplines and specialities involved in this new industry and just as difficult to obtain basic information easily in a convenient form. The appearance from the other side of the Atlantic of such a book as this "*Radiation Hygiene Handbook*", of which the Editor-in-Chief is Hanson Blatz, Director of the New York City office of Radiation Control, and formerly of the A.E.C. Health and Safety Laboratory, is therefore most welcome.

Let no one be deceived by the title of "Handbook", for this is a weighty volume of some 500 odd pages packed with a mass of information, supplied by a team of 38 contributors, each a specialist in his own particular field. There is something for all in this book, in so far as it provides an easy source of reference from which to glean basic information about such subjects as "Radiation Protection Regulations", "Sources of Radiation", "Laboratory Design", "Radiation Detection and Measurements", "Industrial and Research Applications", "Medical Radiation Applications", "Nuclear Safety", "Surface Contamination and Decontamination". Altogether there are 23 sections, of which another is "Personnel Control" which deals very succinctly with personnel selection, medical control, medical records, and medico-legal considerations. As will be gathered from the titles of the sections, this book covers a wide range, and this is the great advantage of such a book for which there has been great need.

Merril Eisenbud writes, in a very pertinent foreword, "The interdisciplinary characteristic of the field creates problems of definition and purpose which must soon be solved if the needs of the expanding nuclear industry are to be met. Who is a radiation hygienist (or, for that matter, what is a health physicist)? What should he know, what should he do, where do his responsibilities begin and where do they end? As our second and third generations of scientists and engineers enter this expanding field our definitions must be improved, our standards for professional qualification must be established and our universities must adapt their curricula for the new requirements that the atomic age imposes." Here, indeed, is food for thought!

Some photographs would have helped to enliven the text; as good as the line drawings are, they suffer, as do the numerous graphs, from being reproduced at too small a scale to be easily and readily appreciated. Several tables are also included, but take up too much space in a work of this nature. It would also be a help if the pages were numbered consecutively from cover to cover for easier reference, instead of being numbered by sections.

It is always a problem to know, not only what to include, but also what to exclude in so protean a work; but our American colleagues have given us a start in this type of radiation hygiene textbook and are to be congratulated on what is no mean feat. Perhaps it may not be too much to hope that we shall see a similar type of compendium compiled in time by our own specialists in this very important sphere of health protection.

N. G. DOUGLAS

A Handbook of Diseases of The Skin, 6th ed. By H. O. Mackey. (Pp. 263; 200 figures. 8*s.* 6*d.*) London and New York: MacMillan & Co. Ltd; Dublin: C. J. Fallon, Ltd.

This is, as described, no more than a handbook, and it does not aim at presenting more than a simple overall picture of the subject. Almost all textbooks of dermatology are bad in that they give the impression that dermatology is something divorced from medicine as a whole and to be approached and treated as something quite foreign. Nevertheless, it is necessary for the student and for the practitioner to have some sort of text on the subject and this handbook has the advantages of being brief, phenomenally cheap and well illustrated, a valuable asset in a dermatological work.

The great majority of the illustrations are remarkably good and, though in black and white, convey the nature of the disease as well as most coloured illustrations, if not better. The text of such a book can with advantage be submitted to surgical excisions and graftings by the reader as his experience grows. The simple facts are here as regards essentials but many old-fashioned ideas are carried over from the past and could be deleted, particularly in the sections on aetiology and treatment. It is not always easy to extract the sound and valuable comment which is often present from other matter which is of doubtful value.

The section on industrial dermatoses is compressed but contains many important points. The chapter on nursing is not good. Many would disapprove the "window" cut in an Unna's paste bandage to "dress" the ulcer; nurses should not be encouraged to wear rubber gloves when handling skin diseases; ointment should not be spread with "tongue blades" and the risk of contagion from scabies in outpatients is not a real one.

There are few errors in the text; the book is well presented and is of a convenient pocket size.

JOHN T. INGRAM

Growing Up in Newcastle upon Tyne. By F. J. W. Miller, S. D. M. Court, W. S. Walton, and E. G. Knox. (Pp. xxi + 369; 23 figures. 25*s*.) Published for the Nuffield Foundation by the Oxford University Press, London. 1960.

This is the second volume in a series of reports on the health of a cohort of children; all those born in Newcastle upon Tyne in the months of May and June, 1947. The first volume, "A Thousand Families in Newcastle upon Tyne" (Spence, Walton, Miller, and Court, 1954), dealt with the situation as seen at the end of the first year. The present book carries the story on to the end of the fifth year, and is therefore concerned entirely with the pre-school child.

Of the 1,142 babies born during the selected period 847 were still in the survey after five years. The authors are justifiably proud of the fact that only seven families withdrew their cooperation. The remaining losses were due to 49 deaths and 239 removals from the city. It is unfortunate that the proportion of children in social classes I and II were reduced from the national average of 18·2% to only 10·3% by the fact that Newcastle's boundaries exclude the residential areas favoured by these classes. On the other hand the predominantly working-class population has provided a sufficiently large sample for comparison (indeed, a dismaying proportion) of children who were judged to lack proper care in one form or another. These children are shown to compare unfavourably in numerous ways with the rest, and although the authors have made a valiant effort to track down just what it is in the family life and inheritance of these less fortunate children which accounts for their different experience, they admit that their findings are far from conclusive. They urge family doctors, public health workers, paediatricians, and those responsible for training doctors and nurses to be aware of the importance of family standards and relationships as a background to any sickness affecting the child.

Another interesting section deals with the acute infective illnesses of childhood and certain differences in their epidemiology which do not appear to have been recognized.

Some disturbing inadequacies in medical knowledge and in parental concern are revealed, and many subjects for further research and postgraduate training are likely to be found in this report, which deserves to be read by all concerned with the welfare of young children. However, it is certainly not easy reading. It would be unfair to criticize it for being involved, because the authors have tried to give a fair picture of a vastly complex subject, though undoubtedly certain criticisms of their presentation could be made and certain of their arguments disputed. The work of the Newcastle team inspires respect for its thoroughness, and this book provides an invaluable record of a period in childhood which ought to be better understood than it is.

MARJORIE CLIFTON

REFERENCE

Spence, J., Walton, W. S., Miller, F. J. W., and Court, S. D. M. (1954). *A Thousand Families in Newcastle upon Tyne: An Approach to the Study of Health and Illness in Children.* Oxford University Press, London.

La Tuberculose des Houilleurs. (Tuberculosis in Coal-miners.) By Jaques Prignot. (Pp. 327; 42 figures; 47 tables. No price given.) Belgium: Éditions Arscia, S. A. 1959.

Opinions about the association of tuberculosis with coal-miners' pneumoconiosis during the past 50 years or so have swung from the thesis that coal dust has a protective action against the tubercle bacillus, to the now strongly held view that all cases of massive fibrosis in coal-miners are tuberculous in origin. Professor Gough has recently written that "the practical point is that every case of massive fibrosis is to be regarded as a potential case of active tuberculosis which is often insidious in origin and concealed clinically". Death in patients with pneumoconiosis usually occurs in the stage of massive fibrosis, and if it is held that dust alone cannot cause fatal pneumoconiosis, the engineer is justified in thinking that dust control is not such an important matter in its prevention, as is the control of tuberculosis. This equally practical point has in fact been put forward by engineers.

On the Continent the "all tuberculosis" concept of massive fibrosis is not held as strongly as it is in this country. In this book, Prignot examines thoroughly and dispassionately most of the available evidence about the association of tuberculosis with coalworkers' pneumoconiosis. In addition to reviewing the work of other investigators, he gives a detailed description of his studies of 180 cases of pulmonary tuberculosis in coalworkers together with many control cases of non-infective coalworkers' pneumoconiosis. He divides the infective cases into four groups according to the radiographic stage of the pneumoconiosis (*pneumoconiose à ombres fines* and *à ombres étendues*) and to the presence or absence of cavitation. The distribution graph of tuberculosis in coal-miners according to age showed a peak between 30 and 40 years and another between 40 and 44 years. As regards length of exposure there were also two peaks, one from five to nine years and the other from 21 to 30 years. The fact that tuberculosis comes on after a short exposure is regarded as contrary to the idea that small doses of coal dust can protect against tuberculosis. In Prignot's first group ("simple" pneumoconiosis with non-cavitated tuberculosis) there were usually no symptoms and the diagnosis was made by radiographic examination. In the second group, with cavitation, the clinical features differed in no way from frank pulmonary tuberculosis. The third group with massive fibrosis without cavitation was nearly identical with cases of non-tuberculous massive pneumoconiosis, whereas the fourth (massive fibrosis with tuberculous cavities) was characterized by clinical evidence of active and progressive tuberculosis. In this group melanoptysis may occur before radiographic evidence of cavitation. Thus, Prignot recognizes a type of massive pneumoconiosis (with coalescent or pseudo-tumoral *x*-ray shadows) which has not been produced by tuberculosis.

Radiographic studies showed that shadows suggesting the presence of tuberculosis appeared at all stages of pneumoconiosis, that both tuberculous and non-infective massive fibrosis occurred predominantly in the right lung,

and that cavities were seen mainly in the posterior parts of the upper and middle lung fields.

Examination of the blood revealed a number of interesting points. The sedimentation rate can be temporarily raised in the non-cavitated forms of non-infective massive fibrosis, but in aseptic or ischaemic necrosis it remains constantly above 20 mm. An isolated high E.S.R. is of no value in the diagnosis of tuberculosis, and amongst the tuberculous coalworkers a constantly high E.S.R. is seen only in those with cavitation. The level of blood fibrogen, which increases with the stage of pneumoconiosis and with cavitation of tuberculous lesions, is occasionally independent of the E.S.R., especially after treatment has been begun. Blood proteins, studied by paper electrophoresis, show a decrease of the albumin and an increase in the globulins, related to the stage of fibrosis. When cavitation is present, the α_2-globulins increase more than the other fractions. The mean level of glycoprotein increases with the stage of pneumoconiosis, with progression of massive fibrosis and in tuberculosis, in which also there is a high glycoprotein-polysaccharide ratio. C-reactive protein was often found in early and advanced massive fibrosis, in aseptic necrosis, and in active tuberculosis. It was concluded that the diagnostic significance of the proteins was limited by great individual variations and by the somewhat similar effect of pneumoconiosis and tuberculosis on them.

The haemagglutination reaction of Middlebrook-Dubos was found to be useful in the differentiation of tuberculous cavitation from the aseptic (or ischaemic) necrosis of massive fibrosis. Prignot regards this fact as being opposed to the thesis that tuberculosis is always responsible for progression in massive fibrosis.

His studies also included the examination of the sputum for tubercle bacilli and dust; the Mantoux reaction; macroscopic and microscopic pathology of the lungs; bronchoscopy; radiography, including tomography and the results of treatment. He recommends that any preventive scheme should include pre-employment radiograph examination and systematic tuberculin tests. Men with negative Mantoux reactions should be vaccinated with B.C.G. until they are positive, and this should be followed by prophylactic chemotherapy.

This important book is (as Professor Lambin says in his graceful introduction) impeccably printed and illustrated, and there are some beautiful coloured reproductions of large sections of coalworkers' lungs prepared in Professor Gough's laboratory at Cardiff. It includes an extensive bibliography, but no index.

A. I. G. McLAUGHLIN.

Elongation Treatment of Low Back Pain. By George S. Hassard, and Charles L. Redd. (Pp. xvi + 78; 47 figures; 36*s*.) Oxford: Blackwell Scientific Publications; Springfield: Thomas. 1959.

This book, intended primarily for physiotherapists and remedial gymnasts, describes a new practical effort towards prevention and treatment of low back pain in industry.

Treatment is based on the idea that a collagen fibrous tissue contracts following injury, and under other conditions. It is claimed that this tissue can be elongated by specialized physical medicine, with relief of symptoms and a 90% reduction of sick leave due to the low back pain.

The authors try to explain, by one pathology, the many conditions affecting the back, but the supporting reasons are unimpressive and not very sound.

The importance of backache in industry is appreciated and good advice is given on correct posture.

In this country we should be opposed to this treatment being carried out by anyone except physiotherapists, but the book suggests that it can be done by nurses, remedial gymnasts and even the works foreman.

Figure 1 shows a typical case of acute disc prolapse but is called sprain of the ligaments and strain of muscle fascia and connective tissue. Figure 5 is incorrectly labelled with regard to the peroneal and sciatic nerves.

At the end of the book which is well produced and attractive all the usual methods of physical medicine are mentioned.

G. P. ARDEN

Filters for Use during Welding and Similar Industrial Operations. British Standard 679 : 1959 and **Equipment for Eye, Face and Neck Protection Against Radiation Arising during Welding and Similar Operations.** British Standard 1542 : 1960. London: British Standards Institution.

British Standard 679 relates to filters for eye protection and includes requirements for quality, for classification for both density and colour (this latter applying only to circular filters for gas welding), for thickness, and for optical uniformity. Methods are given of testing materials for permanence, for resistance to heat and moisture, and for flammability, together with recommendations for the grades of filters to be used for different types of welding. The permissible kinds of materials have been increased to include plastics.

British Standard 1542 specifies requirements for equipment to protect an operator above the shoulders against radiation of wavelength greater than 2000 Å when engaged in welding, cutting, and similar operations. Methods of testing materials are given for resistance to corrosion of metal components, flammability, impact strength of spectacle frames, electrical insulation, and disinfection of equipment. A strong recommendation is put forward that a 4¼ in. × 3¼ in. (108 mm. × 82 mm.) filter should be specified for all new equipment (helmets and shields) intended for use in the United Kingdom.

It is surprising that in this publication emphasis should be laid on infra-red radiation rather than ultra-violet from gas-shielded arc welding and cutting, and vice versa from gas welding and cutting.

These two British Standards are complementary to B.S. 2653 " Protective clothing for welders ", and if the welder is supplied with equipment conforming to their specifications then he will have considerable protection against some of the inherent hazards of the processes he employs.

P. J. R. CHALLEN

Accidents and Ill-health at Work. By John L. Williams. (Pp. 516. 45*s*.) London: Staples Press. 1960.

This is an excellent book. It is the author's contention that the very serious effects of accidents and ill-health at work are quite insufficiently realized and that our methods of dealing with the problem are perfunctory and incomplete. The development of preventive measures in this country has been piecemeal, uncoordinated, anomalous and limited; and we have been slow sometimes to learn from the experience of other countries. Factory and Mine legislation provides a partial answer only to the problem; it is essential that public opinion should be roused, complacency routed, and the community brought to understand the importance of this subject. It is likely that any effective scheme for preventing accidents and ill-health at work will provide for central direction and coordination, with cover for all forms of employment; and there must also be some system in which relevant matters are kept under review, with both employers and employees actively participating. There must also be more research directed to the many problems involving health and safety.

The author has not been content merely to state the problem; he criticizes constructively, and gives his own answers. In an introductory comment, Mr. Williams remarks that he has not dealt comprehensively with his subject: nevertheless, most readers are likely to find that this book gives them far more information than is to be readily obtained elsewhere, and many will doubtless be encouraged to give new thought to this matter.

T. G. FAULKNER HUDSON

Air Pollution Control. By W. L. Faith. (Pp. vii + 259; illustrated. 68*s*.) London: Chapman and Hall; New York: John Wiley and Sons, Inc. 1959.

This book is written by the Managing Director of the Air Pollution Foundation of Los Angeles who makes for it modest but specific claims: it is intended "to present the basic facts that must be considered in any air pollution control program" and, considering that most other books on air pollution have been directed to the specialist, Dr. Faith "has attempted to discuss the various aspects of the problem in language which can be easily understood not only by the technical person not specializing in air pollution but also by the intelligent layman". The text, which would overwhelm most British laymen, makes sporadic concessions to the non-specialized technologist but there are too few instances of such simplification in the many illustrations and tables. Most of these are borrowed from other sources and, unmodified before inclusion, contain much distracting detail which is in direct variance with the author's aim.

It is not surprising that Dr. Faith is at his most fluent and confident in the chapter dealing with automobile exhaust (he uses much local jargon which needs translation) but elsewhere the book is merely a rather uneven précis of published work and as such it merits little criticism of its facts. The book appears to be aimed almost exclusively at an American audience and its value to British readers is correspondingly restricted.

The large bibliography is concerned mainly with American work and is useful, though the convention used is irritating (as in "Drinker, Philip, and Theodore Hatch").

The final chapter on legal aspects is surprisingly parochial and no mention is made of any foreign legislation, such as our Clean Air Act which is regarded as a model ordinance by so many Americans.

The book is well produced but is very expensive, and for the British worker, specialist or not, does not approach in value the Air Pollution Handbook from which so much of its material is admittedly culled.

P. J. LAWTHER

Books Received

(Review in a later issue is not precluded by notice here of books received.)

The Constituents of Tobacco Smoke: An Annotated Bibliography, First Supplement. (Pp. 25.) London: Campbell-Johnson. 1960.

Central Mining—Rand Mines Group Report for the Year 1959. By A. M. Coetzee, Chief Medical Officer. (Pp. 25; with tables.) 1960.

A Synopsis of Public Health and Social Medicine. by A. J. Essex-Cater. (Pp. ix + 576; illustrated. 55*s*.) Bristol: John Wright. 1960.

A Symposium on Industrial Pulmonary Diseases. Edited by E. J. King and C. M. Fletcher. (Pp. viii + 273; 98 figures. 32*s*.) London: J. & A. Churchill. 1960.

British Steel Castings Research Association: Seventh Annual Report, 1960. (Pp. 34; illustrated.) Sheffield. 1960.

Health Plans and Collective Bargaining. By Joseph W. Garbarino. (Pp. xi + 301. 40*s*.) London: Cambridge University Press. 1960.

The Heart in Industry. Edited by Leon J. Warshaw; Foreword by Irving S. Wright. (Pp. 677; 48 figures, 73 tables. $16.00.) New York: Paul B. Hoeber. 1960.

Modern Trends in Occupational Health. Edited by R. S. F. Schilling. (Pp. ix + 313; 46 figures, 34 tables. 67*s*. 6*d*.) London: Butterworth. 1960.

Joint FAO/WHO Expert Committee on Milk Hygiene: Second Report. [Wld. Hlth. Org. techn. Rep. Ser. No. 197.] (Pp. 55. 3*s*. 6*d*.) Geneva: World Health Organization. 1960.

Endemic Goitre. [Wld. Hlth. Org. Monograph Ser. No. 44.] (Pp. 471; illustrated. 40*s*.) Geneva: World Health Organization. 1960.

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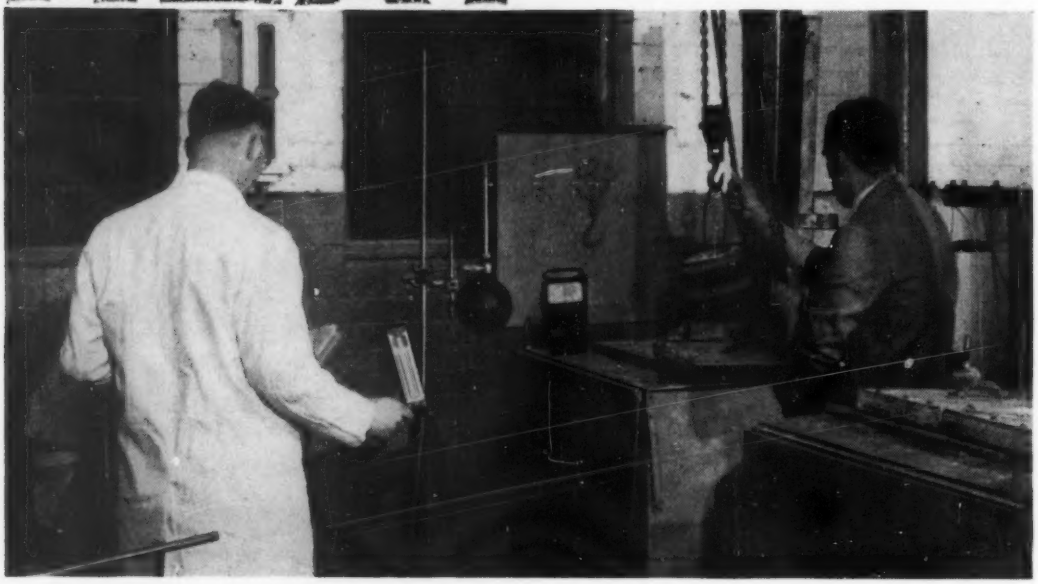

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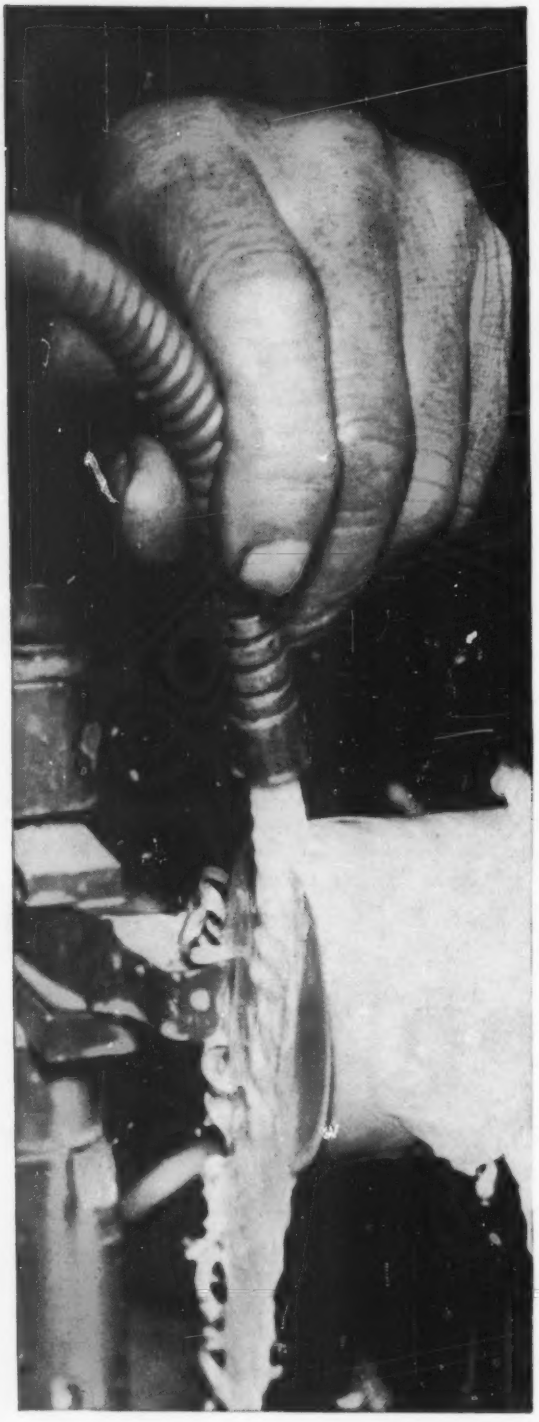

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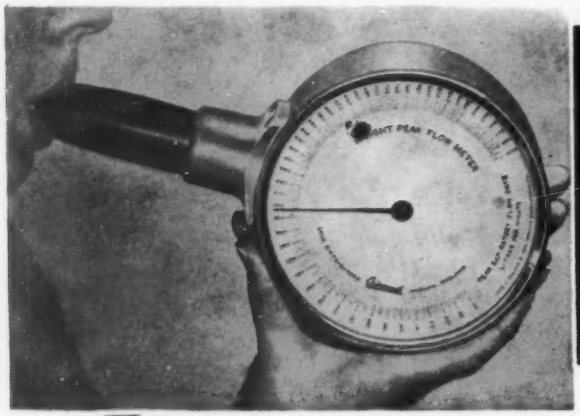

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Brit. Med. J., 1959, **2**, 1041.

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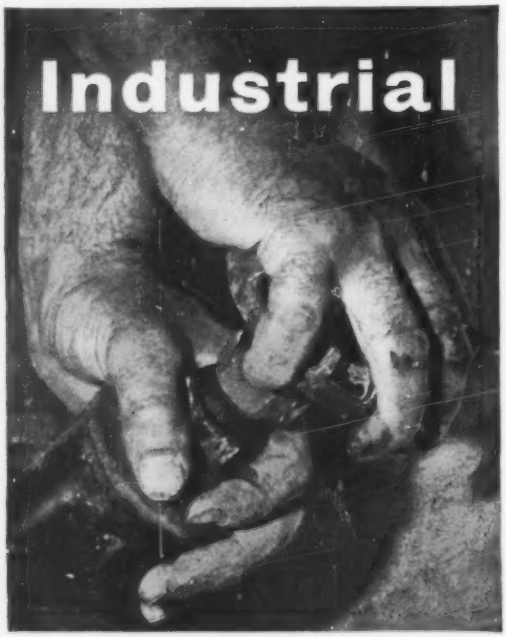

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